PARTS OF THE ORIGINAL DOCUMENT

ARE OF POOR REPRODUCTIVE QUALITY

CERTAINES PARTIES DU DOCUMENT ORIGINAL

SONT DE PIÈTRE QUALITÉ DE REPRODUCTION

REPORT #
RRTAC 87-2

Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Report No. RRTAC 87-2

MINESOIL AND LANDSCAPE RECLAMATION OF THE COAL MINES IN ALBERTA'S MOUNTAINS AND FOOTHILLS

by

A.W. FEDKENHEUER
L.J. KNAPIK
D.G. WALKER

Pedocan Land Evaluation Ltd.

Prepared for

The Mountain-Foothills Reclamation Research Program (MFRRP)

of

THE LAND CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

and

THE COAL ASSOCIATION OF CANADA

1987

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide Government and Industry staff with up-to-date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of the Environment and two Deputy Chairmen from the Department of Forestry, Lands & Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the research program, the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands & Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

Dr. G.A. Singleton, Chairman
Reclamation Research Technical Advisory Committee
Alberta Environment
14th Floor, Standard Life Centre
10405 Jasper Avenue
Edmonton, Alberta T5J 3N4

(403) 427-5815

This report may be cited as:

Fedkenheuer, A.W., L.J. Knapik, and D.G. Walker. 1987. Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. Alberta Land Conservation and Reclamation Council Report 87-2. 174 pp.

Additional copies may be obtained from:

Publication Services
Queen's Printer
11510 Kingsway Avenue
Edmonton, Alberta T5G 2Y5

RECLAMATION RESEARCH REPORTS

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

** 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. 2 vols. L.E. Watson, R.W. Parker, and P.F. Polster. 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habitat, propagation, tolerance, and availability information are provided.

N/A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of the original report conducted in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. 2 vols. H.P. Sims and C.B. Powter. 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981 are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of recently initiated field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop reproduction.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Technical Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

N/A 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. 2 vols. H.P. Sims, C.B. Powter, and J.A. Campbell. 659 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. 2 vols. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 676 pp.

DESCRIPTION: This is a collection of five reports dealing with reestablishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies. An executive summary outlines the findings.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establishe a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to suuport post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North Americal literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe, hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

27. RRTAC 87-1: In prep.

Available from: Publication Services
Queen's Printer
11510 Kingsway Avenue
Edmonton, Alberta T5G 2Y5

* A $5.00 fee is charged for handling and postage.
** A $10.00 fee is charged for handling and postage.
*** A $20.00 fee is charged for handling and postage.
N/A Not available for purchase but available for your perusal at the Alberta Environment Library, 14th Floor, 9820 - 106 Street, Edmonton, Alberta.

FORWARD

UNDER THE AUSPICES OF THE MOUNTAINS AND FOOTHILLS RECLAMATION RESEARCH PROGRAM (MFRRP), PEDOCAN LAND EVALUATION LTD. WAS CONTRACTED TO UNDERTAKE A THOROUGH LITERATURE REVIEW OF MINESOIL AND LANDSCAPE RECLAMATION CONSIDERATIONS FOR THE COAL MINES IN ALBERTA'S MOUNTAINS AND FOOTHILLS AREA. RECOGNIZING THAT THE TERMS OF REFERENCE ENCOMPASSED A WIDER SPECTRUM, A LENGTHY MANUSCRIPT WAS SUBMITTED BY PEDOCAN LAND EVALUATION LTD. IN ORDER TO KEY IN ON AREAS RELATED PRIMARILY TO SOIL AND SOIL RECONSTRUCTION, THE REVEGETATION SUBCOMMITTEE OF MFRRP ELECTED TO EDIT AND CONDENSE THE MANUSCRIPT. IN DOING SO SOME SECTIONS OF ORIGINAL MANUSCRIPT WERE EXCLUDED FROM THIS CONDENSED REPORT. ALL SECTIONS WERE EDITED AND SOMEWHAT RE-ORGANIZED, HOWEVER, THE CONCLUSIONS AND RECOMMENDATIONS ARE THOSE OF THE AUTHORS.

EDITORIAL ASSISTANCE OF MS. JILL PRINGLE, ALBERTA ENVIRONMENT, RESEARCH MANAGEMENT DIVISION, IS GREATLY APPRECIATED. OUR SPECIAL THANKS GO TO MS. LEE MALCOLM, REFORESTATION AND RECLAMATION BRANCH, ALBERTA FOREST SERVICE, WHO TYPED THE CONDENSED MANUSCRIPT.

Members,
Revegetation Sub-committee,
Mountains and Foothills Reclamation
Research Program (MFRRP).

EXECUTIVE SUMMARY

This report provides a review of mined-land reclamation practices and requirements for the Mountain-Foothills Area of Alberta. The review assembled available information useful for making operational reclamation decisions with regard to development of forest stands (forestry use), shrub communities (wildlife habitat), and grassland communities (erosion control).

SECTION 1 of the report discusses the study background, objectives, approach, and general assumptions.

SECTION 2 briefly describes the geographic, geological and ecological setting of this large and diverse region. Discussions of regional climate, soils and vegetation are presented. The region was stratified into three main coal-bearing geological areas to discuss the geology and soils. The vegetation is discussed in the context of four ecoregions: Alpine, Subalpine, Montane, and Boreal Uplands.

SECTION 3 summarizes benchmark plant-soil communities chosen to represent typical grassland, shrubland, and forest ecosystems in this region. The intent in utilizing the benchmark communities is to illustrate the diverse nature of the region and, more importantly, to provide the reclamationist with an understanding of ecosystem characteristics and requirements of post-mine plant communities.

SECTION 4 discusses soil reconstruction considerations and identifies and evaluates the variables that interact to provide successful land reclamation. The variables include climate, soil temperature, evapotranspiration, topography, soil quality, soil physical parameters, soil depth requirements, soil water, soil microflora and fauna (mycorrhizal and non-mycorrhizal), and plant nutrients.

Characteristics of spoil and other materials available for minesoil reconstruction and quality rating systems and proposed guidelines for various soil properties pertinent to grassland and woody plants are presented. Minesoils can be constructed to resemble pre-mine soils, but complete understanding of how minesoils function and change over time requires a great deal of research.

SECTION 5 discusses minesoil construction and management. The material is presented in four subsections: minesoil design and construction, surface control techniques, erosion monitoring, and vegetation establishment and management.

General minesoil design requirements are discussed, and specific requirements for grass-legume cover, willow shrublands, and commercial forests are included. Also discussed are the limitations of bedrock spoil for supporting plant growth and recommendations for minesoil construction in terms of topography development, soil salvage and replacement, and improvement of bedrock spoil without coversoil.

With regard to soil salvage and replacement, coversoil is not necessary for satisfactory reclamation when spoil is of favorable quality as a growth medium.

The major spoil limitations are high rock fragment content at the surface or just below the crushed surface layer, low organic matter content, and high pH (7.5 to 8.0). Each of these conditions can be ameliorated without using coversoil, although costs or risks may favor the use of coversoil. Generally, a rootzone layer of 15 cm minimum is suggested for a grass-legume cover and 20 cm minimum is recommended for forest cover, provided the underlying material meets recommended subsoil design requirements. Surface soil and Regolith can be salvaged as one lift rather than two due to the lack of a strong quality difference in most areas. Two lifts might be considered in locations where large volumes of coversoil are desired.

The subsections on surface control techniques and erosion monitoring discuss the use of mulches, surface manipulation, and vegetation to minimize soil loss by erosion. Monitoring of erosion losses on mine sites is a relatively new science, and ranges from the use of simple field indicators to the use of aerial photogrammetry.

This section concludes with a discussion of vegetation establishment and management. The subsection is divided into two vegetation types: (1) grasses and legumes and (2) trees and shrubs.

SECTION 6 discusses the evaluation of reclamation success. Evaluation of success, post-mine land use, characteristics to measure, success standards, and comparison to standards are discussed and methods are recommended.

It is suggested that evaluation of reclamation success be done in two steps: (1) evaluation of spoil shaping and soil construction, and (2) evaluation of long-term stability. This would assist in early identification of problem areas and early initiation of required remedial action, and perhaps earlier reclamation certification. Success standards should be specific to the mine area and desired end land use(s). Post-mine characteristics should be quantitatively compared to standards specified in an approved reclamation plan.

SECTION 7 discusses the existing information gaps, a review of current research efforts, and recommendations for future research. The areas discussed are categorized into the following: (1) reclamation planning, (2) spoil placement and grading, (3) soil preparation and treatment, (4) spoil-soil-plant interactions, and (5) post-reclamation management.

There are information deficiencies in all of the above areas. There is a considerable amount of research of varying sophistication that is currently being conducted. However, because of differing site-specific objectives of most programs, results cannot currently be extrapolated throughout the Mountain-Foothills region.

A two-stage approach to research is recommended. The fir[illegible] stage involves a comprehensive field study to identify minesoil-site-plant relationships and the effects of management over two growing seasons at several minesites. Evaluation of the results of this study will clarify the specific objectives of a long-term research program. The long-term research program should focus on development of minesoil-plant community growth function models for commercial forest stands of lodgepole pine, white spruce, and other species; wildlife habitats; and erosion-controlling stands of grasses and legumes. The modelling approach forces an understanding of how systems function, which is the key to the prediction of future productivity and the basis of reclamation planning and regulation.

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS i

LIST OF TABLES vi

LIST OF FIGURES ix

ACKNOWLEDGEMENTS x

1.0 INTRODUCTION 1

1.1 Background and Study Objectives 1
1.2 Study Approach 1
1.3 General Assumptions 2

2.0 THE MOUNTAIN-FOOTHILLS STUDY AREA 3

2.1 Geographic Location 3
2.2 Climate 3
2.3 Geology and Soils 6
2.3.1 Upper Jurassic - Lower Cretaceous 6
2.3.1.1 Geology 6
2.3.1.2 Soils 6
2.3.2 Lower Cretaceous 8
2.3.2.1 Geology 8
2.3.2.2 Soils 8
2.3.3 Upper Cretaceous - Lower Tertiary 8
2.3.3.1 Geology 8
2.3.3.2 Soils 9
2.4 Vegetation 10
2.4.1 Plant Communities 10

3.0 BENCHMARK PLANT COMMUNITIES 12

3.1 Herbaceous Communities 12
3.1.1 Summary of Characteristics of Benchmark Grassland Soils 12
3.1.1.1 Revegetation Considerations 14
3.1.1.2 Rooting Medium 14
3.1.1.3 Moisture Levels 14
3.1.1.4 Nutrient Supply 18
3.1.1.5 Limiting Conditions 18

TABLE OF CONTENTS

PAGE

3.2 Shrub Communities 18
3.2.1 Summary of Characteristics of Benchmark Shrub Soils 18
3.2.1.1 Revegetation Considerations 19
3.2.1.2 Rooting Medium 19
3.2.1.3 Moisture Supply 19
3.2.1.4 Nutrient Supply 22
3.2.1.5 Limiting Conditions 22
3.3 Commercial Forest Communities 22
3.3.1 Summary of Characteristics of Benchmark Forest Soils 22
3.3.1.1 Afforestation Considerations 23
3.3.1.2 Rooting Needs 24
3.3.1.3 Moisture Levels 24
3.3.1.4 Nutrient Supply 24
3.3.1.5 Limiting Conditions 24

4.0 SOIL RECONSTRUCTION CONSIDERATIONS 31

4.1 Concepts 31
4.1.1 Options for Soil Reconstruction 31
4.1.2 Soil Salvage and Replacement 33
4.1.3 Horizon Reconstruction 34
4.2 Soil Reconstruction Site Factors 34
4.2.1 Climate 36
4.2.2 Soil Temperature 36
4.2.3 Evapotranspiration 39
4.2.4 Topography 39
4.2.5 Soil Water 40
4.2.5.1 Amount Received 40
4.2.5.2 Infiltration and Movement 41
4.2.5.3 Water Retention 41
4.2.5.4 Soil Moisture Control Section 43
4.3 Rooting Medium Factors 43
4.3.1 Quality 43
4.3.2 Physical Parameters 45
4.3.2.1 Organic Matter 45
4.3.2.2 Porosity 45
4.3.2.3 Texture 46
4.3.2.4 Bulk Density 47
4.3.2.5 Rock Fragments 48
4.3.3 Depth Requirements 49
4.3.3.1 Grasses and Legumes 49
4.3.3.2 Woody Plants 51

TABLE OF CONTENTS

PAGE

4.4 Soil Microflora and Fauna 55
4.4.1 Non-Mycorrhizal Fauna 55
4.4.2 Mycorrhizal Fungi 56
4.5 Plant Nutrients 58
4.5.1 Nutrient Supply 58
4.5.1.1 Cation Exchange Capacity 58
4.5.1.2 pH 58
4.5.1.3 Nitrogen 59
4.5.1.4 Organic Matter 59
4.5.1.5 Phosphorus 61
4.5.2 Prediction of Supply 62
4.5.3 Required Nutrient Level 64
4.6 Other Limiting Conditions 68
4.7 Soil Reconstruction Materials 68
4.7.1 Inventory Methods 68
4.7.2 Quality Rating Guidelines 69
4.7.3 Upper Jurassic - Lower Cretaceous Materials 74
4.7.3.1 Quality 74
4.7.3.2 Changes in Quality with Handling 77
4.7.4 Lower Cretaceous Materials 77
4.7.4.1 Quality 77
4.7.4.2 Changes in Quality with Handling 80
4.7.5 Upper Cretaceous - Lower Tertiary 81
4.7.5.1 Quality 81
4.7.5.2 Changes in Quality with Handling 87
4.8 Summary of Soil Reconstruction Materials 89
4.8.1 Bedrock Overburden 89
4.8.2 Soils 91
4.9 Rate of Soil Formation 93

5.0 MINESOIL CONSTRUCTION AND MANAGEMENT 95

5.1 Minesoil Design and Construction 95
5.1.1 Minesoil Design Requirements 95
5.1.1.1 Minesoil for Grass-Legume Cover 95
5.1.1 2 Minesoil for Willow Shrubland 99
5.1.1.3 Minesoil for Commercial Forests 100
5.1.2 Limitations of Bedrock Spoil 102
5.1.3 Recommendations for Minesoil Construction 105
5.1.3.1 Topography Development 105
5.1.3.2 Soil Salvage and Replacement 106
5.1.3.3 Improvement of Bedrock Spoil Without Coversoil ... 108

TABLE OF CONTENTS

PAGE

5.2 Surface Control Techniques 109
5.2.1 Mulches 109
5.2.2 Surface Manipulation 110
5.2.3 Vegetation 110
5.2.4 Seedbed Preparation 111
5.3 Erosion Monitoring 113
5.3.1 Field Indicators 113
5.3.2 Remote Sensing 113
5.3.3 Measurement of Erosion 114
5.3.4 Soil Loss Estimation 114
5.4 Vegetation Establishment and Management 115
5.4.1 Grasses and Legumes 115
5.4.2 Trees and Shrubs 117

6.0 RECLAMATION EVALUATION 122

6.1 Evaluation of Reclamation Success 122
6.2 Reclamation Approaches 122
6.2.1 Productivity Approach 122
6.2.2 The Capability Approach 123
6.2.3 The Functional Analysis Approach 124
6.3 Characteristics To Measure 125
6.4 Comparison To Standards 127
6.5 Recommended Factors, Standards and Timing 127
6.5.1 Factors To Measure 127
6.5.2 Success Standards 128
6.5.3 Timing 128

7.0 RESEARCH 130

7.1 Information Gaps 130
7.1.1 Reclamation Planning 130
7.1.2 Spoil Placement and Grading 130
7.1.3 Soil Preparation and Treatment 131
7.1.4 Spoil-Soil-Plant Interactions 131
7.1.5 Post-Reclamation Management 132
7.2 Evaluation of Current Reclamation Research 133
7.2.1 Adaptability to Current Gaps 134
7.3 Recommendations and Future Research 135
7.3.1 Spoil Placement and Grading 135
7.3.2 Soil Preparation and Treatment 136
7.3.3 Spoil-Soil-Plant Interactions 136
7.3.4 Post-Reclamation Management 137

TABLE OF CONTENTS

PAGE

GLOSSARY OF TERMS 138

REFERENCES 145

LIST OF TABLES

		PAGE
2.1	Coal-bearing Strata, Alberta Rocky Mountains and Foothills	7
3.1	Benchmark Plant Communities Selected to Evaluate Reclamation Requirements	13
3.2	Montane Grassland Soil Properties	15
3.3	Subalpine Grassland Soil Properties	16
3.4	Alpine Tundra Soil Properties	17
3.5	Boreal Uplands Willow-Birch Community Soil Properties	20
3.6	Montane Willow Community Soil Properties	21
3.7	Montane Douglas Fir/Lodgepole Pine Forest Soil Properties	25
3.8	Boreal Uplands White Spruce Forest Soil Properties	26
3.9	Boreal Uplands Mesic Lodgepole Pine Forest Soil Properties	27
3.10	Boreal Uplands Subxeric Lodgepole Pine/Grass Forest Soil Properties	28
3.11	Subalpine Spruce/Fir Forest Soil Properties	29
3.12	Summary of Forest Soils Characteristics of all Ecoregions	30
4.1	Climatic Factors That Can be Modified by Site Manipulation	37
4.2	Summary of Soil Variables That Interact to Influence the Effective Properties of a Site	44
4.3	Typical Solum Depth of Freely Drained Forest Soils in The Mountain-Foothills Area	52
4.4	Tree Root Distribution in a Balsam Fir Stand	54

LIST OF TABLES

PAGE

4.5 Nitrogen Inputs to a Developing Minesoil 60

4.6 Some Levels of Soil Characteristics for Nutrition of Selected Regeneration Types 66

4.7 Alberta Soils Advisory Committee (1981) Proposed Criteria for Evaluating the Suitability of Soil as Root Zone Material for Revegetation in the Eastern Slopes Region of Alberta 70

4.8 Suggested Approximate Criteria for Evaluating the Quality of Soil Materials for Growth of Conifers and Associated Shrubs in the Eastern Slopes Region of Alberta 71

4.9 Suggested Approximate Criteria for Evaluating the Quality of Soil Materials for Growth of Grasses and Legumes for Erosion Control in the Eastern Slopes Region of Alberta 72

4.10 Proposed Guidelines for Rating the Suitability of Selected Overburden for Use as Coversoil Material in Western Stripmine Reclamation 73

4.11 Estimated Sensitivity of Soil Properties to change During Handling 75

4.12 Upper Jurassic - Lower Cretaceous Soil Reconstruction Materials 76

4.13 Lower Cretaceous Soil Reconstruction Materials - Bedrock Spoil 78

4.14 Lower Cretaceous Region Reconstruction Materials - Regolith 79

4.15 Summary of Data for Selected Topsoil and Regolith Materials at Cardinal River Coal Ltd. Luscar Mine 82

4.16 Upper Cretaceous - Lower Tertiary Region Soil Reconstruction Materials - Bedrock Overburden 83

4.17 Upper Cretaceous - Lower Tertiary Region Soil Reconstruction Materials - Regolith 86

LIST OF TABLES

PAGE

4.18 Key Quality Parameters of Bedrock Overburden and Bedrock Spoil from the Val d'Or mine zone, Coalspur Coalfield 88

4.19 Comparison of Key Soil Quality Paramters by Soil Horizon to Stockpiled, Salvaged Soil Materials 90

4.20 Available Water Capacity of Pre-mine Soils and Typical Soil Construction Materials 92

5.1 Summary of Key Minesoil Requirements to Provide Favorable Quality 96

5.2 Quality Ratings of Bedrock Spoil for Use as Benchmark Plant Community Rootzone Materials 103

LIST OF FIGURES

PAGE

2.1 Location of Major Coalfields and Coal Mines in the Mountain-Foothills Area 4

2.2 Location of Coal-bearing Geological Formations in the Mountain-Foothills Area 5

2.3 Distribution of Ecoregions in the Mountain-Foothills Area 11

4.1 Minesoil Construction Options 32

5.1 Soil Loss Ratio versus Litter Cover (%) in Relation to Canopy Cover and Plant Height 112

5.2 Hypothetical Maintenance Fertilization Scheme to Restore Soil Fertility and Encourage Plant Succession Toward the Establishment of Native N-fixers on Disturbed Lands in the Mountain-Foothills Region 118

ACKNOWLEGEMENTS

The original report was prepared under a contractual arrangement with The Coal Association of Canada and Alberta Land Conservation and Reclamation Council. The definition of the project, data compilation, and report preparation has involved the assistance of many people. We would like to acknowledge the project managers, Dr. S. Takyi (Alberta Forest Service) and T.A.B. Adamson (Obed Mountain Coal Co.). We would also like to thank R. Ferster (Luscar Ltd.) and Dr. P. Ziemkiewicz (RRTAC) and the other members of the Revegetation Subcommittee of the Mountain Foothills Reclamation Research Program for their direction and report review. We are grateful to W. Russell and R. Annas for their assistance in compiling and analyzing data.

A special thank you goes to B. Knapik for putting the original report together, and to some understanding families during the many "extra" hours.

1. INTRODUCTION

1.1 BACKGROUND AND STUDY OBJECTIVES

The rehabilitation of coal-mined land in the mountains and foothills of Alberta is a rapidly developing field. It is based on a relatively few years of experience, and techniques adapted from other areas. This report (1) reviews the state-of-the-art of reclamation with regard to site and soil reconstruction and re-establishment of biological productivity and (2) identifies needs and opportunities for research in the Mountain-Foothills Area to fill existing data gaps.

The primary aim of this review is to assemble information to enable operational reclamation decisions to be made, to provide for tree growth (forestry use), shrub growth (wildlife habitat), and herbaceous cover (erosion control). The review is to also identify information gaps and recommend research needed to fill those gaps.

Keeping in mind the high operational reclamation costs often encountered, this review attempts to acquire facts that provide information to undertake reclamation in the most cost-efficient manner possible. This review provides information to:

1. Enable reasonable reclamation standards to be developed;
2. Identify soil requirements for plant growth;
3. Identify optimum post-mine landforms and topography to re-establish watershed values and control surface water runoff;
4. Improve minesoil management to enhance productivity; and
5. Develop procedures for the evaluation of success in minesoil construction.

1.2 STUDY APPROACH

To evaluate minesoil rehabilitation, the following general framework has been used:

1. Evaluation of climatic, topographic, and soil and vegetation properties that affect slope stability, erosion, plant growth, and aesthetics.

2. Evaluation of soil construction materials, minesoil design criteria, materials handing, and soil construction and management procedures that will meet the stated objectives; and

3. Appreciation of the limitations (and opportunities) afforded by mining method and economics.

1.3 GENERAL ASSUMPTIONS

It is assumed that the objectives of site and soil reconstruction are as follows:

1. Achievement of specific land use potential;

2. Slope and surface stabilization, control of wind and water erosion, and protection of surface water and groundwater resources;

3. Development of productive, self-sustaining ecosytems similar to pre-mine ecosystems;

4. Optimum use of soil materials suitable for plant growth; and

5. Development of a landscape that is aesthetically pleasing.

All objectives are important for every mine and on all sites at a mine, but their relative importance and level of requirement may vary considerably over a single mine lease and between mines.

2. THE MOUNTAIN-FOOTHILLS STUDY AREA

2.1 GEOGRAPHIC LOCATION

The general area considered in this review includes the Mountain and Foothills Coal Regions as defined by the Alberta Energy Resources Conservation Board (ERCB Map 84-31) 1984 and the Swan Hills area (Figure 2.1).

There are many coal fields in the area (Figure 2.1), but useful information on soils, geology, reclamation, and growth of trees and other plants is readily available for only a few of these. The characteristics of the area have therefore been defined by examining selected sites that are representative of larger regions. The coal fields with the most useful data are Tent Mountain, Cadomin-Luscar, Smoky River, Obed Mountain, Coalspur, and Swan Hills. Quantitative data from the these areas have been extrapolated to characterize the pre-mine soils and overburden materials for the entire area.

The literature from a much broader geographic area relating to reclamation of mined land and the associated disciplines of soil science and plant ecology has been reviewed to develop an understanding of the relevant practices and principles.

2.2 CLIMATE

Several systems of climate classification have been developed which include parts or all of the Mountain-Foothills Area (Koppen 1936; Longley 1970; MacIver 1981; MacIver at al. 1972; Powell and MacIver 1977; Sanderson 1948; Strong and Leggat 1981). Strong and Leggat (1981) attempted to integrate vegetation, soils and climate data in an ecological classification. Although this work has been criticized for its failure to achieve truly distinctive climatic regions (MacIver 1981), it is widely used and forms the framework for much of the land classification work done by the Alberta Government. Thus it has been adopted for this study.

Strong and Leggat (1981) recognized four ecoregions in the commercial coal-bearing areas of the Mountain-Foothills Area (Figure 2.2). In decreasing order of average annual precipitation, they are: Alpine > Subalpine > Boreal Uplands > Montane.

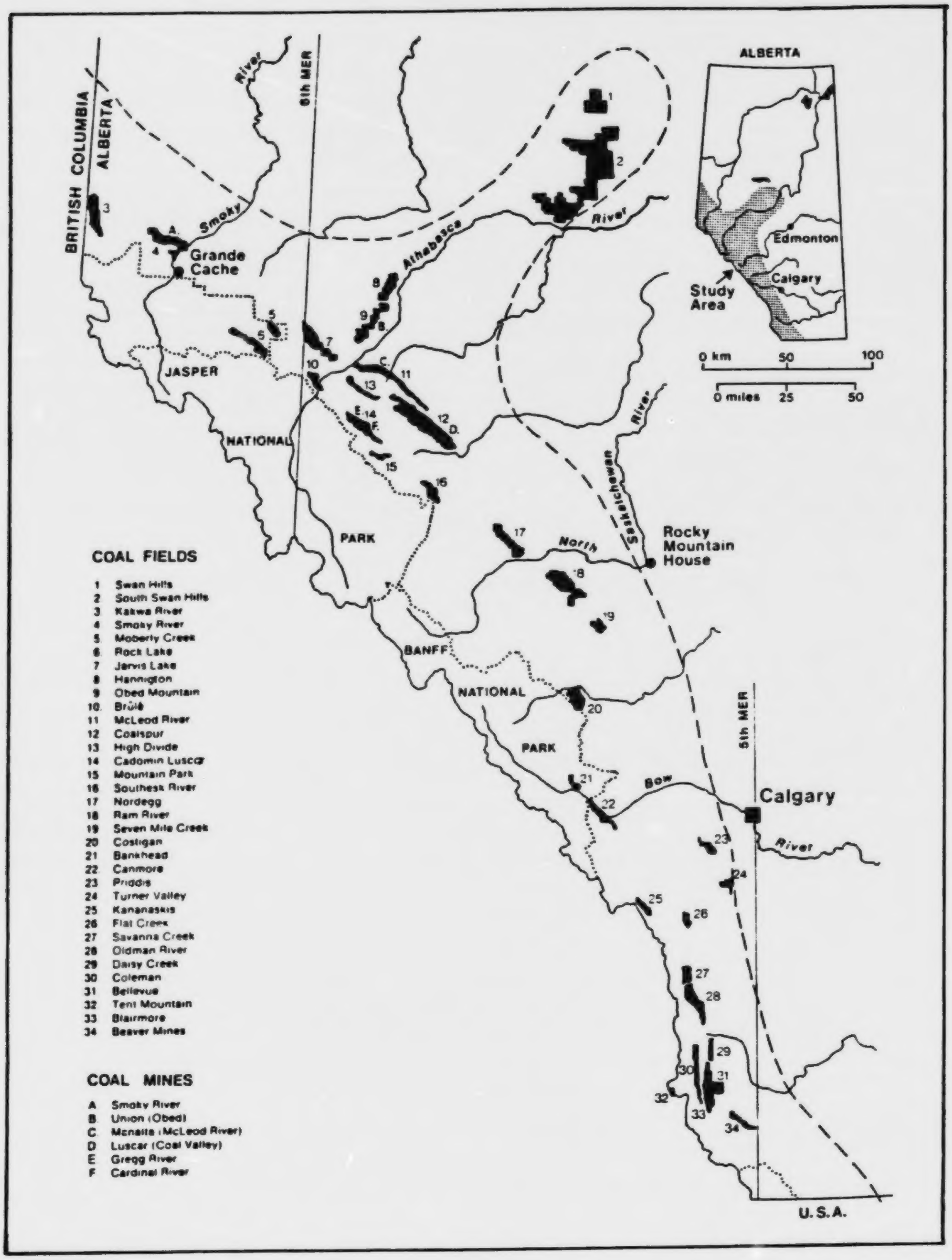
BRITISH COLUMBIA
ALBERTA
6th MER
5th MER
Smoky River
Athabasca River
Grande Cache
JASPER NATIONAL PARK
BANFF NATIONAL PARK
North Saskatchewan River
Rocky Mountain House
Bow River
Calgary
U.S.A.
ALBERTA
Edmonton
Calgary
Study Area
0 km 50 100
0 miles 25 50
COAL FIELDS
1 Swan Hills
2 South Swan Hills
3 Kakwa River
4 Smoky River
5 Moberly Creek
6 Rock Lake
7 Jervis Lake
8 Hannigton
9 Obed Mountain
10. Brûlé
11 McLeod River
12 Coalspur
13 High Divide
14 Cadomin Luscar
15 Mountain Park
16 Southesk River
17 Nordegg
18 Ram River
19 Seven Mile Creek
20 Costigan
21 Bankhead
22 Canmore
23 Priddis
24 Turner Valley
25 Kananaskis
26 Flat Creek
27 Savanna Creek
28 Oldman River
29 Daisy Creek
30 Coleman
31 Bellevue
32 Tent Mountain
33 Blairmore
34 Beaver Mines
COAL MINES
A Smoky River
B Union (Obed)
C Mcnalla (McLeod River)
D Luscar (Coal Valley)
E Gregg River
F Cardinal River

Figure 2.1 Location of major coalfields and coal mines in the Mountain-Foothills Area (after Energy Resources Conservation Board, Map 84-31).

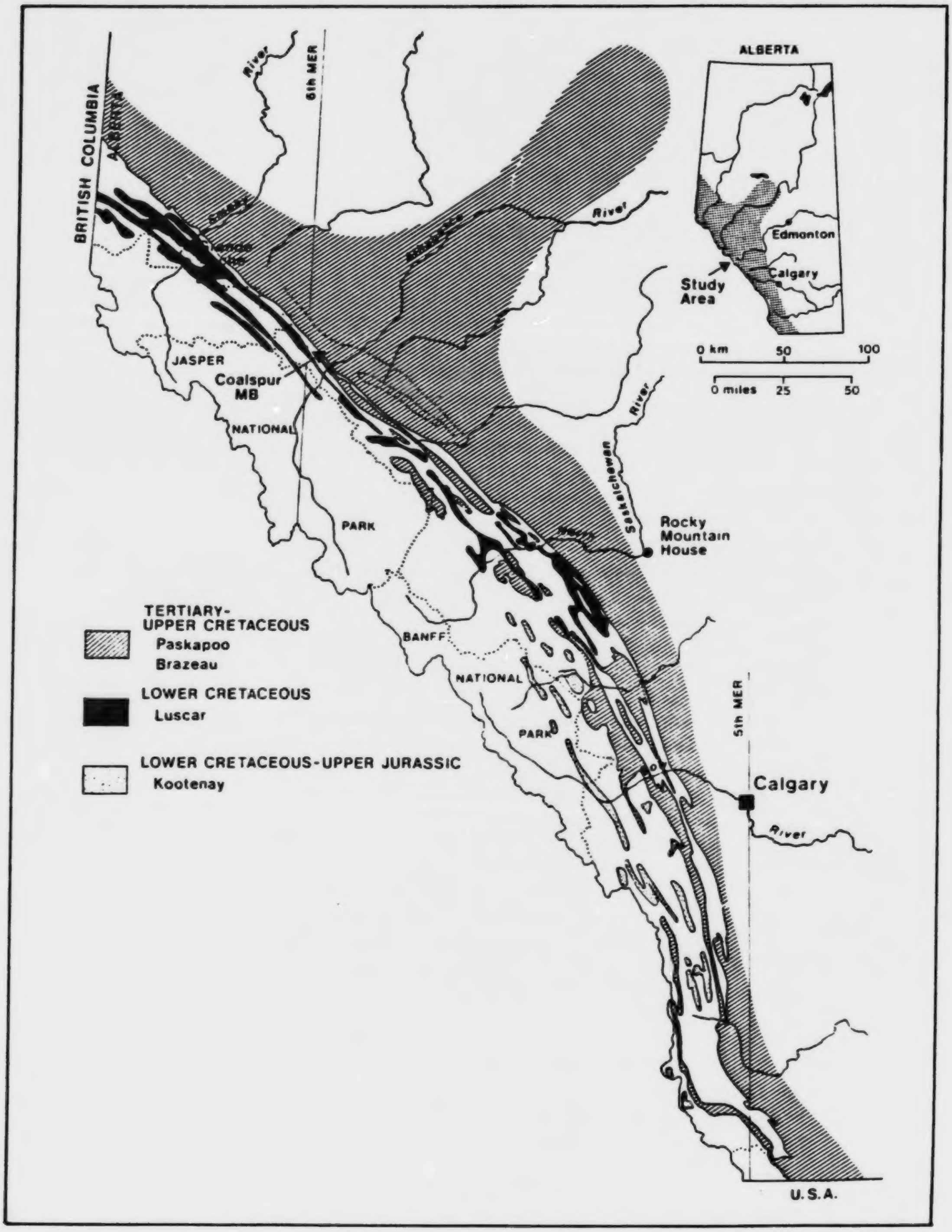
BRITISH COLUMBIA
ALBERTA
River
6th MER
Smoky
Grande Cache
Athabasca
River
JASPER
Coalspur MB
NATIONAL
PARK
Saskatchewan
River
Rocky Mountain House
BANFF
NATIONAL
PARK
5th MER
Calgary
River
U.S.A.
ALBERTA
Edmonton
Calgary
Study Area
0 km 50 100
0 miles 25 50
TERTIARY-UPPER CRETACEOUS
Paskapoo
Brazeau
LOWER CRETACEOUS
Luscar
LOWER CRETACEOUS-UPPER JURASSIC
Kootenay

Figure 2. 2 Location of coal-bearing geological formations in the Mountain-Foothills Area (Source: ERCB 1983).

2.3 GEOLOGY AND SOILS

The geology of the coal-bearing formations and the overburden is of particular importance for land reclamation after surface mining, as it defines the materials available for use in reclamation efforts. The following subsections characterize the overburden materials of the coal fields in the Mountain-Foothills Area as shown in Figure 2.2.

2.3.1 Upper Jurassic - Lower Cretaceous

2.3.1.1 Geology

The oldest coal-bearing strata in the Alberta Rocky Mountains are located in the Mist Mountain Formation (Gibson 1979), which forms part of the Kootenay Group of Upper Jurassic - Lower Cretaceous age (Table 2.1). The coal-bearing Kootenay Group strata are exposed in the Rocky Mountains in southern Alberta and were mined in the Coleman, Blairmore, and Tent Mountain coal fields.

The overburden mined in these areas is the nonmarine Cadomin Formation which is composed of quartzite-chert pebble conglomerate with locally prevalent medium to very coarse grained sandstone and in some instances mudstone, siltstone, and fine grained sandstone. The thicker conglomerate and sandstone beds are believed to be of alluvial fan and fluvial origin.

2.3.1.2 Soils

Soils developed from these geological materials have distinctive characteristics in each of the Montane, Subalpine, and Alpine regions. The Montane region includes the river valleys with gravelly and sandy glaciofluvial terraces and floodplains and the lower mountain slopes with till blankets overlying bedrock and local colluvial deposits. Forest soils are Luvisols and Brunisols with shallow (often less than 30 cm) profile development, and subsoils are usually strongly calcareous. Grassland soils are extensive in many valleys, and are typically Regosols or Rego Chernozemics with a thin, dark, humus-enriched A horizon overlying strongly calcareous C horizons. Most soils have very high coarse fragment content and high pH (Dumanski et al. 1972; Knapik 1974; Pettapiece 1971).

Soils of the Subalpine region occur primarily on steeply sloping mountain sides where thin till and colluvial veneers overlie hard bedrock. Rock outcrops are common. Forest soils most commonly have Luvisolic or Brunisolic profiles with acid surface horizons, calcareous or acid subsoil, and high coarse fragment content. Soil profile thickness is usually in the range of 20 to 40 cm. Grassland soils, which occur on some southern aspects, usually have thin Ah horizons and very shallow depth to bedrock.

Table 2.1 Coal-bearing strata, Alberta Rocky Mountains and Foothills*

			COAL SEAMS	COALFIELDS
TERTIARY	UNCONFORMITY			
	SAUNDERS GROUP (Central Alberta)	PASKAPOO FM		
		COALSPUR BEDS	▬▬▬	COALSPUR, McLEOD, OBED MOUNTAIN
UPPER CRETACEOUS		BRAZEAU FM		
	ALBERTA GROUP (Central Alberta)	WABIABI FM		(Outer Foothills - Plains)
		CARDIUM FM		
		BLACKSTONE FM		
LOWER CRETACEOUS	DISCONFORMITY			
	LUSCAR GROUP (Northern and North Central Alberta)	GATES FM	▬▬▬▬	CADOMIN-LUSCAR, MOUNTAIN PARK, SMOKY RIVER, QUINTETTE MOUNTAIN (B.C.)
		MOOSEBAR FM		
		GLADSTONE FM		
		CADOMIN FM		(Inner Foothills)
	UNCONFORMITY			
	KOOTENAY GROUP (Southern Alberta)	ELK FM		BLAIRMORE, COLEMAN, TENT MOUNTAIN
- - - - -		MIST MOUNTAIN FM	▬▬▬	
UPPER JURASSIC		MORRISSEY FM		(Mountains)
		FERNIE FM		

* Adapted from Gibson (1979), Jerzykiewicz and McLean (1980), and Langenberg and McMechan (in press).

Alpine soils occur above the treeline in discontinuous areas on thin veneers of colluvium and weathered bedrock overlying hard bedrock. Brunisolic and Regosolic soils with thin Ah horizons and high coarse fragment content are intermixed with extensive rock outcrops. Soil depths and vegetation cover relate to slope position, wind exposure, and snow patterns, but soil profile thickness seldom exceeds 20 cm.

2.3.2 Lower Cretaceous

2.3.2.1 Geology

The Cadomin-Luscar, Mountain Park, and Smoky River coal fields of the inner Foothills are situated in a coal-bearing member of the Gates Formation, which forms part of the Lower Cretaceous Luscar Group (Langenberg and McMechan, in press). Due to gradual facies changes, the Luscar Group grades laterally into the essentially non-coal-bearing strata of the Blairmore Group (McLean 1982) in the area of the Clearwater River. Consequently there are no important Lower Cretaceous coal deposits in the inner Foothills south of the Clearwater River.

2.3.2.2 Soils

Soils of the Lower Cretaceous geological area are typically found in the Subalpine and Alpine regions. Subalpine soils have developed in veneers of till and colluvium overlying bedrock. Depth to bedrock is usually greater on lower slope positions and in valleys than on upper slopes where soils are shallow and often very stony. Some thick glaciofluvial deposits and till occur in valley bottoms. Thin peat accumulations are present in some poorly drained areas. Forest soils have Brunisolic or Luvisolic profiles of 30 to 40 cm thickness. The sola are usually strongly acid, but subsoils may be acid or calcareous. Soils tend to have high coarse fragment content, especially in upper slope positions.

Alpine soils occur above treeline in a few discontinuous areas. Shallow Brunisols and Regosols are developed in veneers of stony colluvium or weathered bedrock overlying hard bedrock. Rock outcrops or colluvial deposits with no soil development cover much of the land surface.

2.3.3 Upper Cretaceous - Lower Tertiary

2.3.3.1 Geology

Coal seams of major importance occur within the Coalspur beds (Jerzykiewicz and McLean, 1980). Major deposits within the region include the Coalspur, McLeod River and Obed Mountain coalfields.

The Coalspur beds contain a zone of coarse grained sandstones, conglomeratic sandstones, and conglomerates (the Entrance Conglomerate) at their base. This conglomeratic unit is overlain by a sequence of interbedded mudstones and sandstones that underlie the Coal Zone. The Coal Zone consists of coal seams interbedded with carbonaceous shale, claystone/mudstone, siltstone, and medium - coarse grained sandstone units. The sandstones are massively bedded in places, and the coal, carbonaceous shale and claystone units may contain bentonite beds.

Most lithofacies consist of thin bedded and laminated alternating layers of a few centimetres to one or two metres thick. The bentonite layers range from a few millimetres to 50 cm or rarely, more. They are commonly best preserved where interbedded with coal. These volcanogenic beds are usually rich in montmorillonitic clay minerals, but some are predominantly kaolinite and are classified as tonsteins. Tonsteins are always associated with coal or carbonaceous beds (Jerzykiewicz and Mclean, 1980).

The Coalspur beds are overlain by more resistant sandstone, siltstone, and mudstone of the lower Tertiary Paskapoo Formation. Near the base, the Paskapoo Formation contains conglomerate units.

2.3.3.2 Soils

The Upper Cretaceous - Lower Tertiary geological area falls in the Boreal Uplands ecoregion (Strong and Leggat, 1981). Soils of the Foothills section are developed in thin, stony till veneers overlying bedrock on the ridges, and in thin-to-thick deposits of till and glaciofluvial or glaciolacustrine sediments in the valleys. Peat accumulations of variable thickness are common in poorly drained valleys and depressional areas. Luvisolic and Brunisolic soils have developed under lodgepole pine or white spruce forests. Soil profiles have developed to a 30 or 40 cm depth, and are usually strongly acid (Dumanski et al. 1972; Knapik and Burton 1980). Subsoils may be acidic or calcareous, depending largely on the local geology. Gleysolic and Organic soils occur in poorly drained locations.

In the Western Alberta Plains soils are developed primarily in till that varies greatly in thickness but tends to be thicker than in the Foothills. The underlying bedrock is usually deeply weathered soft sandstones and mudstones that often outcrop on steep slopes and escarpments.

A discontinuous blanket of cobbly gravel occurs between the till and the bedrock in some of the coal field areas. Forest soils under lodgepole pine or mixed spruce stands have Luvisolic profiles developed to depths of 50 to 80 cm (Brocke 1981b; Dumanski et al. 1972; Esso 1979). Poorly drained Gleysols and Organic soils with variable depths of peat are locally important. Coarse fragment content is variable, but can be very high in areas where the gravel layer is present. Soils are generally acid in the surface layers but are calcareous in the subsoil.

2.4 VEGETATION

2.4.1 Plant Communities

The Alpine Ecoregion (Strong and Leggat, 1981) lies above the treeline which ranges in elevation from 1880 m on north-facing slopes in the north to 2280 m on south-facing slopes in the south (Figure 2.3). The vegetation is dominated by grasslands and dwarf shrublands. Vegetation patterns and areas of active erosion are strongly influenced by exposure to wind and snow patterns (Baig 1972; Knapik et al. 1973).

The Subalpine Ecoregion is often divided into lower and upper levels to separate the predominantly closed forest of Engelmann spruce and alpine fir from the open forest in the upper reaches that grade into alpine tundra. Forest stands have low productivity, but some stands in the lower Subalpine areas can reach merchantable volumes (Corns 1978). Fescue or Elymus grasslands occur on some steep, south-facing slopes (Corns and Achuff 1982; Kojima 1984; Ogilvie 1976; Russell et al. 1984; Strong and Leggat 1981).

The Montane Ecoregion occurs mainly in the southern Foothills and in major river valleys of the Rocky Mountains (Corns and Achuff 1982; Strong and Leggat 1981). Elevationally it occurs above the fescue grassland and aspen parkland and below the Subalpine at elevations between 1000 and 1600 m. Douglas fir (*Pseudotsuga menziesii*) and limber pine (*Pinus flexilis*) dominated forests and extensive grasslands distinguish the Montane from other regions in the Mountain-Foothills Area.

The Boreal Uplands Ecoregion occurs at lower elevations than the subalpine in the Foothills and outer mountain ranges, and on high benchlands of the Western Alberta Plains. Closed coniferous forest dominates the landscape, with both white and black spruce (*Picea glauca*, *P. mariana*) being climax species on mesic sites. Aspen (*Populus tremuloides*) forests are restricted to southerly aspects with drier moisture regimes.

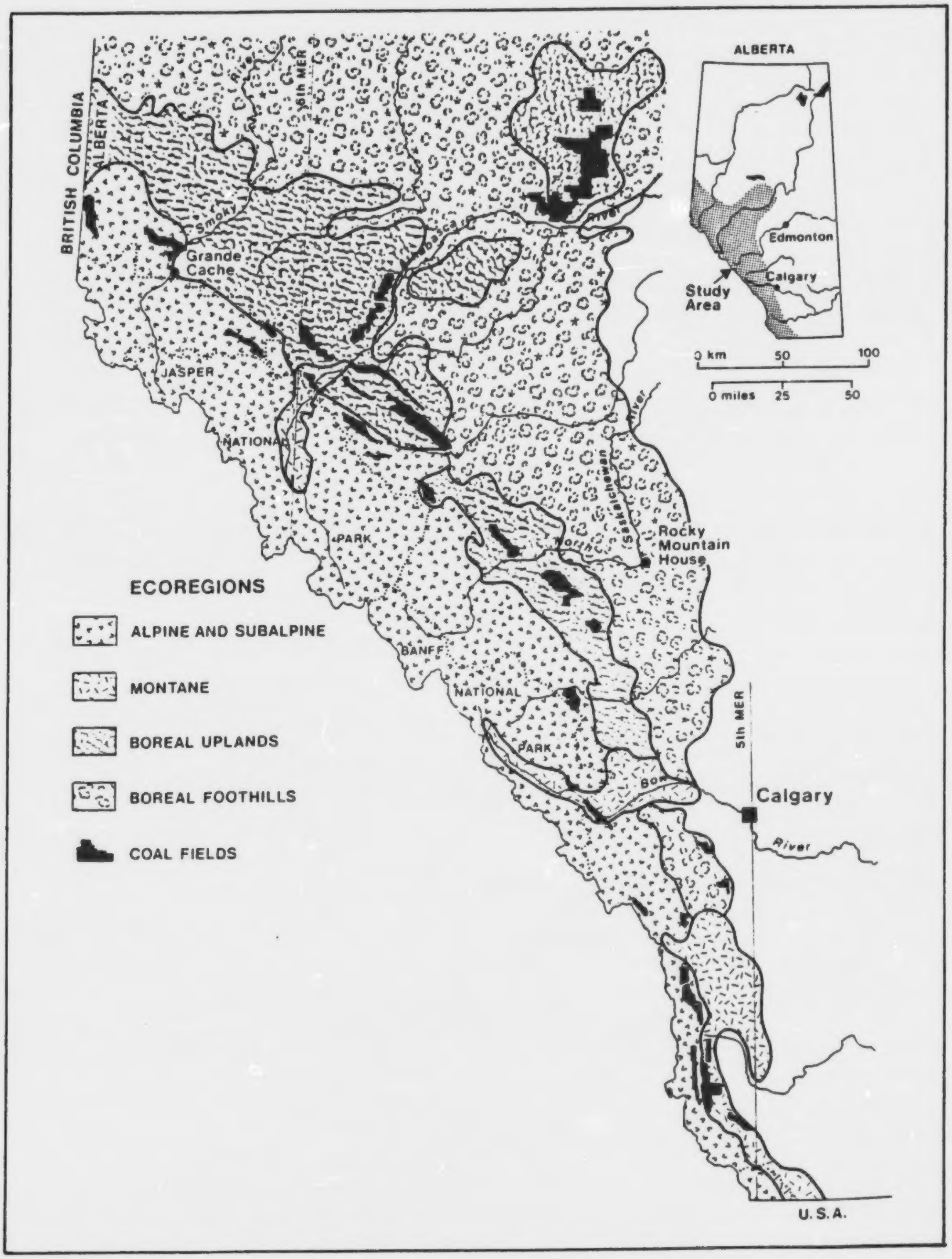
ALBERTA
BRITISH COLUMBIA
ALBERTA
Smoky
River
5th MER
Grande Cache
Athabasca
River
JASPER
NATIONAL
PARK
North
Saskatchewan
River
Rocky Mountain House
BANFF
NATIONAL
PARK
Bow
5th MER
Calgary
River
U.S.A.
Edmonton
Calgary
Study Area
0 km 50 100
0 miles 25 50
ECOREGIONS
ALPINE AND SUBALPINE
MONTANE
BOREAL UPLANDS
BOREAL FOOTHILLS
COAL FIELDS

Figure 2. 3 Distribution of ecoregions in the Mountain-Foothills Area (after Strong and Leggat, 1981).

3.0 BENCHMARK PLANT COMMUNITIES

To focus our efforts regarding rehabilitation requirements for various land uses and post-mine ecosystems, we have considered the location of coal deposits and mining activities (from ERCB Report 84-31, 1984) in relation to pre-mining ecosystems (Figure 2.3). A number of ecosystems (Table 3.1) were selected to serve as benchmarks for evaluating soil-vegetation-wildlife function and rehabilitation requirements.

The benchmark plant communities represent typical ecosystems encountered in the Mountain-Foothills coalfields. The site and soil properties of these modal (typical) types provide goals for reclamation. Reclaimed soils that have similar characteristics, and therefore similar function, can be considered to have equal capability to the pre-mine soils. Development of some of the quality characteristics in minesoils will take a period of time to match those of well-developed pre-mine soils. The length of time required and the levels of sufficiency are the issues that control management inputs during reclamation.

The benchmark communities (Table 3-1) are not intended to be a complete list of possible plant-soil communities found in the region, but are some of the dominant ones encountered. The soil data listed for each benchmark represent modal (typical) sites. No ranges of soil properties for each type have been identified as this information is not available due to the standard practice of sampling typical sites. Most modal site data represent means of several sites within an area. The content of nutrients and exchangeable ions are reported as the usual concentration values and also as mass per unit surface area to enable comparison of soils with very different bulk density values.

3.1 HERBACEOUS COMMUNITIES

3.1.1 Summary of Characteristics of Benchmark Grassland Soils

The A horizon of grassland soils (benchmark communities 1, 2 and 4) is typically 15 to 20 cm thick, with low bulk density, high macroporosity, and low soil strength. Fine soil volume is 70 to 85 percent with a loamy particle size class. The AWC (Available Water Capacity) is 2 to 4 cm in the top 20 cm. Reaction is 6.5 to 7, and CEC (Cation Exchange Capacity) is 20 to 25 me/100 g of fine soil. This horizon contains 4 to 15 percent organic carbon and C/N ratios are low (8 to 13).

The C horizon (the second horizon of these soils) is of variable thickness to bedrock and has variable rock content, but solid bedrock is often encountered within 50 cm. Fine soil volume is usually greater than 40 percent and the soil family particle size class is loamy-skeletal. Effective rooting depth varies from

Table 3.1 Benchmark plant communities selected to evaluate reclamation requirements.

ECOREGION	PRE-MINE TYPE	MOISTURE REGIME	SOIL FAMILY	LANDSCAPE POSITION
Alpine	1. Tundra	subxeric-mesic	Lithic Dystric Brunisol, coarse loamy, mixed, alkaline, calcareous, cold lithic phase	various slopes and aspects with persistent snow cover
Lower Subalpine (southern)	2. Grassland	xeric-subxeric	Orthic Eutric Brunisol, coarse loamy, mixed, alkaline, calcareous, cold	steep, south aspect, upper slope
Lower Subalpine (northern)	3. Spruce/Fir	submesic-mesic	Brunisolic Gray Luvisol, fine loamy, mixed, acid cold	gentle to steep north aspect
Montane (southern)	4. Grassland	xeric-submesic	Orthic Humic Regosol, loamy-skeletal, mixed, alkaline, calcareous, cold	gentle slopes, all aspects
	5. Douglas fir/ Lodgepole pine	xeric-subxeric	Eutric Brunisol, coarse loamy-skeletal, mixed, alkaline, calcareous, cold	level to steep south aspect
	6. Willow	hygric	Gleysol, loamy, mixed, neutral, cold	depressional, valley bottom
Boreal Uplands (northern)	7. Lodgepole pine	mesic	Brunisolic Gray Luvisol, fine loamy, mixed, acid, cold	gentle slopes, all aspects
	8. Willow/Birch	hygric	Gleysol, loamy, mixed, neutral, cold	depressional, valley bottom
	9. Lodgepole pine/Grass	submesic-subxeric	Eluviated Eutric Brunisol, loamy-skeletal, mixed, alkaline, cold (lithic)	hilltops or steep south aspect, upper slope
	10. White spruce	mesic	Brunisolic Gray Luvisol, fine loamy, mixed, neutral, weakly calcareous, cold	gentle slopes, northerly aspects

15 to 45 cm, which varies with plant species and site conditions. Soil reaction is neutral to alkaline (pH 6.5 to 7.9) and the horizons typically have low CEC (8 to 15 me/100 g of fine soil) and low organic carbon. Benchmark grassland soil properties are presented in Tables 3.2, 3.3, and 3.4.

3.1.1.1 Revegetation Considerations

The major limiting factors to plant establishment and productivity in natural Alpine ecosystems are short growing season, low summer temperatures, and low fertility. The tolerance of alpine species to specific environmental factors is virtually unknown. It is known that shaping, contouring, fertilizing, mulching, seeding, and planting techniques can alter edaphic and microclimatic factors of disturbed lands to meet the physiological tolerance limits of plants adaptable to the ecoregion.

In Subalpine and Montane Ecoregions the growing season is longer and more heat units are available for plant growth. Grasslands vary in site locations from valley bottoms to steeply sloping southern aspects, which affects moisture and nutrient regimes of the site. Site factors are often more important in determining growth rates and succession trends than are soil factors. As in Alpine areas, the tolerance limits of adaptable species to soil quality under varying site conditions is largely unknown.

Research and demonstration trials at various locations have shown that various management practices can provide suitable edaphic and microclimatic conditions on reclaimed sites to meet the physiological tolerance limits of adaptable plants, at least for the short term.

3.1.1.2 Rooting Medium

Average effective rooting depth in Alpine soils is 15 cm, which increases to 35 cm in Montane and 45 cm in Subalpine grassland soils. Considerable variability in depth does occur, however. A minimum soil depth for acceptable rooting might be 15 to 20 cm of favorable material overlying spoil that is permeable and has finer than fragmental particle size. Favorable material will have at least 40 to 50 percent fine soil volume and bulk densities of 1.0 to 1.4 g/cm^3.

3.1.1.3 Moisture Levels

Moisture levels are related to climatic, site, and edaphic characteristics and plant species requirements. The ecological moisture regime of Montane and Subalpine benchmark types is xeric, and vegetation is adapted to frequent and prolonged moisture stress. The Alpine benchmark type has subxeric to mesic ecological moisture regime and can have periods of moisture

Table 3.2 Montane grassland soil properties.

ECOREGION: MONTANE (Southern)

	MODAL SOIL		
HORIZON	Ah	Ck1	Ck2
DEPTH (cm)	0 to 16	16 to 57	57 to 83
Rooting and Water Supply			
Bulk Density (g/cm^3)	0.9	1.0	1.7
Macroporosity (%)	---	---	---
Family Particle Size Class	loamy	loamy-skeletal	loamy-skeletal
Surface Strength	low	---	---
Fine Soil (<2 mm) Volume (%)	76	58	43
Available Water Capacity (cm)	---	---	---
Effective Rooting Depth (cm)	---	35 (variable 13 to 65)	---
Soil Moisture Control Section (cm)	---	---	---
Soil Moisture Regime	--------- non-leaching --------		
Nutrient Supply			
Reaction (pH)	7.0	7.5	7.8
CEC (me/100 g)	21.0	8.6	4.0
(E/m2/horizon)	30	35	---
Exchangeable Bases (%)	100	100	100
(E/m2/horizon)	30	35	---
Organic C (wt.%)	4.2	1.5	---
(g/m2/horizon)	6000	6200	---
C:N Ratio	13*	13*	---
Total N (wt.%)	0.3	0.1	---
(g/m2/horizon)	430	400	---
Limiting Conditions			
Salinity	--------- non-saline ----------		
Sodicity	--------- non-sodic -----------		
High Lime (wt.%)	1.3	1.0	1.7

* = assumed value

Pre-mine data sources: Coen and Holland (1976); Pettapiece (1970).

Table 3.3 Subalpine grassland soil properties.

ECOREGION: SUBALPINE (Southern, Lower, and Upper Subalpine)

	MODAL SOIL		
HORIZON	Ah	C1	C2
DEPTH (cm)	0 to 18	18 to 65	65 to 14
Rooting and Water Supply			
Bulk Density (g/cm^3)	1.0	1.1	1.2
Macroporosity (%)	high	high	high
Family Particle Size Class	--- loamy ----		variable
Surface Strength	low	---	---
Fine Soil (<2 mm) Volume (%)	85	80	80 (variable)
Available Water Capacity (cm)	1.9	5	5 (var.,3 to 19 vol. %)
Effective Rooting Depth (cm)	--------- 45 -------------		
Soil Moisture Control Section (cm)	------- variable ----------		
Soil Moisture Regime	------- non-leaching ------		
Nutrient Supply			
Reaction (pH)	6.7	6.5	6.6
CEC (me/100 g)	25.2	17.7	18.7
(E/m2/horizon)	45	91	---
Exchangeable Bases (%)	87	87	87
(E/m2/horizon)	39	79	---
Organic C (wt.%)	15.6	2.1	2.2
(g/m2/horizon)	1560	230	280
C:N Ratio	13*	-- no data --	
Total N (wt.%)	1.2*	-- no data --	
(g/m2/horizon)	---	---	---
Limiting Conditions			
Salinity	------ non-saline ------		
Sodicity	------ non-sodic -------		
High Lime (wt.%)	0	0.5	0.7

* = assumed value

Pre-mine data sources: Coen and Holland (1976)

Table 3.4 Alpine Tundra soil properties.

ECOREGION: ALPINE

	MODAL SOIL			
HORIZON	Ah	Bm	Ck	R
DEPTH (cm)	0 to 12	12 to 20	20 to 30	30+
Rooting and Water Supply				
Bulk Density (g/cm^3)	0.6	0.8	1.6	---
Macroporosity (%)	high	high	low	---
Family Particle Size Class	--- loamy ---		loamy-skeletal	---
Surface Strength	low	---	---	---
Fine Soil (<2 mm) Volume (%)	50 to 70	40 to 80	var.	---
Available Water Capacity (cm)	3 to 4	2	2(var.)	---
Effective Rooting Depth (cm)	15			
Soil Moisture Control Section (cm)	---	---	---	---
Soil Moisture Regime	non-leaching			
Nutrient Supply				
Reaction (pH)	6.7	7.3	7.9	---
CEC (me/100 g)	27.7	10.4	3.3	---
(E/m2/horizon)	12	4	3	---
Exchangeable Bases (%)	95	100	100	---
(E/m2/horizon)	11	4	3	---
Organic C (wt.%)	4.7	0.8	---	---
(g/m2/horizon)	2000	300	---	---
C:N Ratio	8	7	---	---
Total N (wt.%)	0.6	0.1	---	---
(g/m2/horizon)	260	40	---	---
Limiting Conditions				
Salinity	non-saline			
Sodicity	non-sodic			
High Lime (wt.%)	low to very high			

Pre-mine data sources: Holland and Coen (1982); Knapik (1973).

stress. Available water capacity in the effective rooting depth of the soils is variable, with a mean value of approximately 2 to 4 cm in the surface 15 to 20 cm depth. The soils have nonleaching soil moisture regimes. These soils occur on exposed, upper slope positions with southern to western aspect. Water supply is mainly from rainfall.

3.1.1.4 Nutrient Supply

The surface horizons of grassland soils have accumulations of organic carbon (4 to 15 percent by weight) and C:N ratios of 8 to 13. Soil pH tends to be in the neutral range (6.5 to 7) and CEC and base saturation are high. The role of subsoil horizons in supplying nutrients is unknown, but subsoils tend to have alkaline pH, high base saturation, and low organic carbon levels.

3.1.1.5 Limiting Conditions

The tolerance of most relevant grassland species to levels of specific environmental factors is virtually unknown. Revegetation species selected for a site must be tolerant of the climatic and site factors present. The limiting soil chemical characteristics in soil reclamation materials may be low pH of some pre-mine soils, high pH of some bedrock spoil, and (possibly) high sodicity of spoil from isolated areas.

3.2 SHRUB COMMUNITIES

3.2.1 Summary of Characteristics of Benchmark Shrubland Soils

The Shrubland benchmark communities (numbers 6 and 8, Table 3.1) have strong site control factors, being located in valley bottom or cove slope positions where seepage and ponded run-off waters contribute to high moisture and nutrient levels.

Boreal Uplands willow/birch shrubland soils have an LFH organic horizon overlying an Ahg of approximately 13 cm thickness with high organic carbon content and low bulk density. The A, B, and C horizons are usually loamy to fine loamy with high fine soil volume. The entire profile is neutral to slightly acidic, and cation exchange capacity and base saturation levels are high. The soils have a saturated moisture regime, with the watertable within rooting depth for most of the growing season. Run-on and seepage waters and fresh sediments supply high levels of nutrients.

Montane willow shrubland soils have site and soil characteristics very similar to the Boreal Uplands types. The soil profiles tend to be less well developed, and the benchmark type is a Rego Gleysol, without A or B horizons. Soil pH levels are neutral to slightly alkaline and CEC and exchangeable base levels are high. Moisture and nutrient regimes are similar to Boreal Uplands types. Benchmark shrubland soil properties are given in Tables 3.5 and 3.6.

3.2.1.1 Revegetation Considerations

Establishment of willow shrubland types similar to the benchmarks will require careful site selection and development of site characteristics as well as soil properties. These shrubland types require hygric moisture regimes and high levels of nutrients, which can be provided in basins or cove slopes where run-on and seepage waters are ponded to suitable depths for suitable periods of time. Watertable levels should be held within the effective rooting depth for most of the growing season. The rooting depth of willow shrubs will increase with age to greater than 1 m, but young stands will probably need a watertable within 20 to 30 cm of the surface. Careful grading will be needed to ensure sites are not destroyed by prolonged ponding or deep flooding.

The soils on these sites will aggrade during the early post-mine period due to accumulation of sediments eroded from surrounding slopes. This process could be helpful in developing a surface horizon with high fine soil volume.

3.2.1.2 Rooting Medium

Willow shrubland soils provide sufficient fine soil volume with low bulk density and strength, and high porosity for aeration above a watertable for root growth and activity. The depth to growing season watertable has not been reported, but is estimated at approximately 0.3 m in the benchmark types.

3.2.1.3 Moisture Supply

Moisture supply to willow shrublands is dependent on a hygric ecological moisture regime and a phreatic surface within the rooting depth. The watertable is within 30 to 50 cm of the surface of soils that have properties conducive for capillary rise of water to the shrubs. The soil parameters listed for rooting needs should provide a satisfactory soil water regime. The soil moisture regime is saturated.

Table 3.5 Boreal Uplands willow-birch community soil properties.

ECOREGION: BOREAL UPLANDS

	MODAL SOIL			
HORIZON	LFH	Ah(g)	Bg(t)	C
DEPTH (cm)	6 to 0	0 to 13	13 to 36	26+
Rooting and Water Supply				
Bulk Density (g/cm^3)	0.1*	0.8*	1.5*	1.8*
Macroporosity (%)	high	high	---	---
Family Particle Size Class	loamy			
Surface Strength	low	low	---	---
Fine Soil (<2 mm) Volume (%)	---	100	60 to 100	
Available Water Capacity (cm)	no data			
Effective Rooting Depth (cm)	no data			
Soil Moisture Control Section (cm)	---	---	---	---
Soil Moisture Regime	saturated			
Nutrient Supply				
Reaction (pH)	6.8	5.8	5.6	6.7
CEC (me/100 g)	71.9	29.6	21.0	20.5
(E/m2/horizon)	4.3	3.1	41	---
Exchangeable Bases (%)	79	81	92	97
(E/m2/horizon)	3.4	25	38	---
Organic C (wt.%)	28.1	5.7	1.3	1.2
(g/m2/horizon)	1700	6000	2500	---
C:N Ratio	15	11	12	12
Total N (wt.%)	1.9	0.6	0.1	0.1
(g/m2/horizon)	110	620	200	---
Limiting Conditions				
Salinity	non-saline			
Sodicity	non-sodic			
High Lime (wt.%)	non-calcareous			

* = assumed value

Pre-mine data sources: Annas et al. (1983); Robertson et al. (1984).

Table 3.6 Montane willow community soil properties.

ECOREGION: MONTANE (Southern) also in Lower Subalpine

	MODAL SOIL		
HORIZON	LF(Oh)	Ckg1	Ckg2
DEPTH (cm)	13 to 0	0 to 25	25 to 42+
Rooting and Water Supply			
Bulk Density (g/cm^3)	0.1*	1.6*	1.6*
Macroporosity (%)	high	low	low
Family Particle Size Class	loamy		
Surface Strength	low	---	---
Fine Soil (<2 mm) Volume (%)	---	100	100
Available Water Capacity (cm)	no data		
Effective Rooting Depth (cm)	no data		
Soil Moisture Control Section (cm)	---	---	---
Soil Moisture Regime	saturated		
Nutrient Supply			
Reaction (pH)	7.3	7.4	7.5
CEC (me/100 g)	---	34.1	22.0
(E/m2/horizon)	---	140	---
Exchangeable Bases (%)	---	100	100
(E/m2/horizon)	---	140	---
Organic C (wt.%)	37.4	4.1	2.3
(g/m2/horizon)	48000	16000	---
C:N Ratio	50 to 60*	---	---
Total N (wt.%)	---	---	---
(g/m2/horizon)	---	---	---
Limiting Conditions			
Salinity	non-saline		
Sodicity	non-sodic		
High Lime (wt.%)	8.6	29.5	30.1

* = assumed value

Pre-mine data sources: Coen and Holland (1976); Holland and Coen (1982).

3.2.1.4 Nutrient Supply

Nutrient pools in these soils are frequently replenished by nutrients in run-on waters and, in some cases, continually by groundwater seepage. Soil pH levels range from slightly acidic to slightly alkaline. Organic matter accumulations are usually present on the surface of these cold, wet soils. Organic matter typically has high C:N ratios in surface layers.

3.2.1.5 Limiting Conditions

With provision of proper moisture regime and nutrient supply, most limiting conditions may not apply in these stands. Willow shrublands have established naturally on strongly sodic spoil at Sterco and appear to be growing well. Willow stands also establish naturally on strongly calcareous materials, so high carbonate content is probably not limiting.

3.3 COMMERCIAL FOREST COMMUNITIES

3.3.1 Summary of Characteristics of Benchmark Forest Soils

The typical freely drained soils (benchmark communities 3, 5, 7, 9 and 10) under forest cover in the Boreal Uplands, Montane, and Subalpine ecoregions have several common properties, typical of the Luvisolic and Brunisolic soil orders, that relate to climatic and vegetation influences (Dumanski et al. 1972; Pettapiece 1970; Strong and Leggat 1981; Twardy and Corns 1980). Luvisolic soils typically have an LF, Ae, Bt, BC, C horizon sequence, and Brunisolic soils have an LF, Ae, Bm, C horizon sequence.

The solum (the L-F, A and B horizons) defines the depth of pedogenic and biochemical activity, and can be thought of as the active layer. The fibrimor L-F and the Ae have low soil strength and high total and macro porosity. The B horizon often has high bulk density and high soil strength, and limited permeability to roots, water, and air. The BC horizon is transitional to the geological parent material - the C horizon. The C horizon contributes water to deeply rooted plants and may supply some nutrients (Comerford et al. 1984; McColl 1984).

The characteristics of the surface organic (L-F-H) layer of forest soils is very different from that of "topsoil" (Ah) horizons of grassland soils. Forest soils in the Mountain-Foothills Area have predominantly more humus form with fibrimor being the most common on freely drained sites. The organic material consists of L (weakly decomposed leaves, twigs, and woody materials) and F (partly decomposed leaves, twigs, and woody materials) at most sites, with content of H (decomposed organic matter) increasing in wetter sites to form a humimor. H materials are the only ones considered humified. The fibrimor humus layer of forest soils is a source of organic matter of poor quality with high C:N ratio and low CEC and low AWC on a volume basis.

The Ae horizon has high silt and fine sand content, but is subject to crusting when exposed. The Bt or Bm horizons are the most suitable horizons in terms of water retention capacity due to loamy to fine loamy textures in most situations. The BC and C horizons tend to have higher coarse fragment content, especially on upper slope positions in the Foothills and Mountains, which limits their quality. Benchmark forest communities soil properties are given in Tables 3.7 to 3.11. A summary of forest soil characteristics of all Ecoregions is presented in Table 3.12.

3.3.1.1. Afforestation Considerations

As with grassland and shrubland minesoils, the development of minesoils for forestry must consider climatic, topographic and surface and near-surface water movement in addition to soil factors. Site location and modification and tree species selection can override many edaphic factors and can mean the difference between establishment success and failure. Slope position and aspect, and microsite preparation can often have more effect on moisture regime for a tree seedling than soil depth or available water storage capacity.

Many options exist for reforestation and soil management, including seeding; planting container or bareroot seedlings; planting wildlings; planting directly into a prepared minesoil; planting into a cover crop of grass or grass-legume; various fertilizer programs; and combinations of all of these and other strategies.

Given the considerable effects of site selection (in macro, meso, and micro scales), tree species selection, and soil and vegetation management options, any attempt to identify specific soil requirements without stating the management assumptions and site conditions is senseless.

The benchmark forest types provide a natural integration of the climatic and site factors in the pre-mine landscape, and it is assumed analogous climatic and site factors will exist on the equivalent post-mine site. Certain management procedures must also be assumed, including:

1. Tree species and genetic stock will be selected to be compatible with site conditions;

2. Trees will be fertilized for initial establishment and probably for the early growth period;

3. Tree seedlings will not experience strong competition from grasses; and

4. Appropriate mycorrhizae will be established on tree roots.

3.3.1.2 Rooting Needs

The effective rooting depth of most forest types is approximately 30 to 50 cm, with the majority of the fine roots concentrated in the upper 5 to 10 cm. Surface layers have low bulk density, low strength, high porosity, and high fine soil volume, which are conducive to good root growth. Colonization by the appropriate mycorrhizae is also necessary for proper root function.

3.3.1.3 Moisture Levels

The ecological moisture regimes of the benchmark forest communities vary from xeric in Montane Douglas Fir/lodgepole pine forests to mesic and subhygric in the Boreal Uplands white spruce forest type. Moisture regime is largely determined by local climate and site position, but edaphic properties modify these controls. Soil moisture regimes vary from nonleaching to saturated; and water supply to the site varies from primarily rainfall on xeric sites to rainfall plus snowmelt, run-on, and seepage on subhygric sites.

3.3.1.4 Nutrient Supply

Coniferous forest soils have acid surface horizons with low base saturation, and pH may or may not increase to neutral or alkaline in the B and C horizons. The surface organic horizon (LF) has high organic carbon content (25 to 40 percent) on a weight percentage basis, but this converts to only moderate amounts on a weight per unit area basis. The organic matter in the typical mor horizons also has high C:N ratios, indicating immobilization of nutrients. The CEC of the Ae and upper B horizons of forest soils is usually in the range of 12 to 20 me/100 g of fine soil, with most forest soils having a total CEC to a depth of 20 cm (including LF, Ae, and upper B) of approximately 50 E/m^2. Base saturation in this depth is usually 40 to 60 percent of the CEC.

3.3.1.5 Limiting Conditions

Limiting site conditions can often be ameliorated by species selection and shaping and microsite manipulation. Soil physical conditions that provide rooting and water supply will provide suitable conditions. Soil chemical properties that could limit growth of conifers include high pH (pH to 5.5 preferred), high carbonate content (usually accompanies high pH), and high sodium in the rootzone (again indicated by high pH). Levels at which minor elements may be deficient or toxic are unknown.

Table 3.7 Montane Douglas fir/lodgepole pine forest soil properties.

ECOREGION: MONTANE (Southern)

	MODAL SOIL			
HORIZON	LF	Ae	Bm(t)	BC(k)
DEPTH (cm)	2 to 0	0 to 9	9 to 21	21 to 41
Rooting and Water Supply				
Bulk Density (g/cm^3)	0.08*	1.3*	1.4*	1.7*
Macroporosity (%)	high	high	---	---
Family Particle Size Class	---	--- loamy ---		loamy to loamy-skel.
Surface Strength	low	low	---	---
Fine Soil (<2 mm) Volume (%)	---	>65	>65	often >50
Available Water Capacity (cm)	------------- no data -------------			
Effective Rooting Depth (cm)	---	---	40	---
Soil Moisture Control Section (cm)	------------- no data -------------			
Soil Moisture Regime	---	non-leaching		---
Nutrient Supply				
Reaction (pH)	5.9	6.1	6.4	7.4
CEC (me/100 g)	44	14.7	19.0	24.8
(E/m2/horizon)	0.3	17.2	32	84
Exchangeable Bases (%)	---	51	90	100
(E/m2/horizon)	---	8.8	29	84
Organic C (wt.%)	41	1.7	1.5	1.2
(g/m2/horizon)	660	2000	2500	4100
C:N Ratio	---	25	20	---
Total N (wt.%)	---	- no data -		---
(g/m2/horizon)	---	- no data -		---
Limiting Conditions				
Salinity	----------- non-saline -----------			
Sodicity	----------- non-sodic -----------			
High Lime (wt.%)	---	---	3.8	44

* = assumed value

Pre-mine data sources: Coen and Holland (1976); Holland and Coen (1982); Pettapiece (1970).

Table 3.8 Boreal Uplands white spruce forest soil properties.

ECOREGION: BOREAL UPLANDS

	MODAL SOIL				
HORIZON	LF	Ae	Bt	BC	C
DEPTH (cm)	8 to 0	0 to 8	8 to 32	32 to 60	60+
Rooting and Water Supply					
Bulk Density (g/cm^3)	0.1*	1.2*	1.6*	1.6*	1.8*
Macroporosity (%)	high	high	---	---	---
Family Particle Size Class	---------- loamy to clayey ----------				
Surface Strength	low	low	---	---	---
Fine Soil (<2 mm) Volume (%)	---	100	90	(70-90)	
Available Water Capacity (cm)	------------- no data ---------------				
Effective Rooting Depth (cm)	--------------- 50 -----------------				
Soil Moisture Control Section (cm)	---	---	---	---	---
Soil Moisture Regime	------------- leaching --------------				
Nutrient Supply					
Reaction (pH)	5.5	5.1	5.3	5.6	6.6
CEC (me/100 g)	68	13.3	17.1	14.1	17.9
(E/m2/horizon)	5.4	13	66	63	---
Exchangeable Bases (%)	62	50	82	100	100
(E/m2/horizon)	3.3	6.5	54	63	---
Organic C (wt.%)	31	1.2	0.7	0.4	---
(g/m2/horizon)	2500	1200	2700	1800	---
C:N Ratio	34	15	12	13	---
Total N (wt.%)	0.9	0.08	0.06	0.03	---
(g/m2/horizon)	70	77	230	130	---
Limiting Conditions					
Salinity	----------- non-saline -----------				
Sodicity	----------- non-sodic ------------				
High Lime (wt.%)	---------- non-calcareous --------				

* = assumed value

Pre-mine data sources: Dumanski et al. (1972); Knapik and Burton (1980); Robertson et al. (1984).

Table 3.9 Boreal Uplands mesic lodgepole pine forest soil properties.

ECOREGION: BOREAL UPLANDS

	MODAL SOIL				
HORIZON	LF	Ae	Bm	Bt	BC
DEPTH (cm)	8 to 0	0 to 9	9 to 23	23 to 44	44 to
Rooting and Water Supply					
Bulk Density (g/cm^3)	0.1*	1.2*	1.3*	1.6*	1.9*
Macroporosity (%)	high	high	---	---	---
Family Particle Size Class	loamy				
Surface Strength	low	low	---	---	---
Fine Soil (<2 mm) Volume (%)	---	90	70-85		
Available Water Capacity (cm)	---	---	---	---	---
Effective Rooting Depth (cm)	50				
Soil Moisture Control Section (cm)	---	---	---	---	---
Soil Moisture Regime	leaching				
Nutrient Supply					
Reaction (pH)	4.6	4.5	5.1	5.2	5.3
CEC (me/100 g)	66.3	12.9	14.3	17.2	21.9
(E/m2/horizon)	5.3	14	26	62	73
Exchangeable Bases (%)	36	38	38	74	82
(E/m2/horizon)	1.8	5.3	10	46	60
Organic C (wt.%)	24	1.1	0.9	0.05	0.04
(g/m2/horizon)	1900	1200	1600	1700	1500
C:N Ratio	36	17	13	13	13
Total N (wt.%)	0.6	0.06	0.07	0.04	0.03
(g/m2/horizon)	53	70	120	130	120
Limiting Conditions					
Salinity	non-saline				
Sodicity	non-sodic				
High Lime (wt.%)	non-calcareous				

* = assumed value

Pre-mine data sources: Holland and Coen (1982); Robertson et al. (1984).

Table 3.10 Boreal Uplands subxeric Lodgepole pine/grass forest soil properties.

ECOREGION: BOREAL UPLANDS (also in Montane and Lower Subalpine)

	MODAL SOIL				
HORIZON	LF	Ae	Bm	BC	Ck
DEPTH (cm)	4 to 0	0 to 4	4 to 20	20 to 29	29+
Rooting and Water Supply					
Bulk Density (g/cm^3)	0.1	1.2	1.5	1.6	2.1
Macroporosity (%)	high	high	---	---	---
Family Particle Size Class	---	loamy			
Surface Strength	low	low	---	---	---
Fine Soil (<2 mm) Volume (%)	---	90	90	85	---
Available Water Capacity (cm)	0.1	0.6	3.2	1.8	---
Effective Rooting Depth (cm)	50				
Soil Moisture Control Section (cm)	14 to 40				
Soil Moisture Regime	non-leaching				
Nutrient Supply					
Reaction (pH)	5.0	5.2	6.2	7.4	7.5
CEC (me/100 g)	65.3	11.8	21.2	22.1	13.6
(E/m2/horizon)	2.6	5.7	50	12	---
Exchangeable Bases (%)	74	87	100	100	100
(E/m2/horizon)	1.9	4.9	50	12	---
Organic C (wt.%)	38.1	1.4	1.2	1.7	1.0
(g/m2/horizon)	1500	670	2900	2500	---
C:N Ratio	36	18	17	14	---
Total N (wt.%)	1.1	0.08	0.07	0.12	---
(g/m2/horizon)	22	45	170	180	---
Limiting Conditions					
Salinity	non-saline				
Sodicity	non-sodic				
High Lime (wt.%)	---	---	---	---	---

Pre-mine data sources: Holland and Coen (1982); Kojima (1984); REAP Veg. & Soil Data Bank, Robertson et al. (1984).

Table 3.11 Subalpine spruce/fir forest soil properties.

ECOREGION: SUBALPINE (Lower)

	MODAL SOIL				
HORIZON	LF	Ae	Bm(k)	BC(k)	Ck
DEPTH (cm)	11 to 0	0 to 7	7 to 19	19 to 47	47+
Rooting and Water Supply					
Bulk Density (g/cm^3)	0.1*	1.2*	1.6*	1.6*	---
Macroporosity (%)	---	---	---	---	---
Family Particle Size Class	loamy				loamy-skel.
Surface Strength	low	low	---	---	---
Fine Soil (<2 mm) Volume (%)	---	--- usually >80 —			40 to 80
Available Water Capacity (cm)	0.3a	1.0a	2.4	5.8	---
Effective Rooting Depth (cm)	30				
Soil Moisture Control Section (cm)	13 to 38				
Soil Moisture Regime	weakly leaching				
Nutrient Supply					
Reaction (pH)	3.8	5.1	6.3	6.7	7.6
CEC (me/100 g)	81.1	20.0	24.7	17.7	4.6
(E/m2/horizon)	8.9	17	47	82	---
Exchangeable Bases (%)	40	48	57	56	100
(E/m2/horizon)	3.6	8.2	27	46	---
Organic C (wt.%)	42.4	2.7	2.5	1.2	1.4
(g/m2/horizon)	4700	2300	4800	5600	---
C:N Ratio	42	27	12	12	---
Total N (wt.%)	1.0	0.1	0.2	0.1	---
(g/m2/horizon)	110	84	380	460	---
Limiting Conditions					
Salinity	non-saline				
Sodicity	non-sodic				
High Lime (wt.%)	---	0.3	23	46	47

* = assumed value

Pre-mine data sources: Holland and Coen (1982); Kojima (1984); LaRoi and Hnatiuk (1980).

Table 3.12 Summary of forest soils characteristics of all Ecoregions.

	MODAL SOIL			
HORIZON	LF	Ae	Bt(m)	BC(k)
THICKNESS (cm)	2 to 10	4 to 9	10 to 25	10 to 30
Rooting and Water Supply				
Bulk Density (g/cm^3)	0.08	1.2	1.6	1.8
Macroporosity (%)	high	high	low	low
Family Particle Size Class	fibric	loamy	loamy	loamy to loamy skel.
Surface Strength	low	low	high	high
Fine Soil (<2 mm) Volume (%)	---	>60	>60	>40
Available Water Capacity (cm)	0.3	1	2.5	5
Effective Rooting Depth (cm)	30 to 50			
Soil Moisture Regime	non-leaching to leaching			
Nutrient Supply				
Reaction (pH)	3.8 to 5.5	4.5 to 6.1	5.1 to 6.4	5.2 to 7.4
CEC (me/100 g)	40 to 80	12 to 20	14 to 25	13 to 25
(E/m2/horizon)	0.3 to 9	6 to 17	14 to 66	70 to 80
Organic C (wt.%)	24 to 42	1.1 to 2.7	0.7 to 2.5	0.05 to 1.7
(g/m2/horizon)	600 to 4700	700 to 2300	1600 to 4800	1500 to 5600
C:N Ratio	34 to 42	15 to 27	12 to 20	12 to 14
Total N (wt.%)	0.6 to 1.1	0.06 to 0.1	0.06 to 0.2	0.03 to 0.1
(g/m2/horizon)	20 to 110	45 to 84	170 to 380	130 to 460
Limiting Conditions				
Salinity	non-saline			
Sodicity	non-sodic			

4. SOIL RECONSTRUCTION CONSIDERATIONS AND MATERIALS

4.1 CONCEPTS

4.1.1 Options for Soil Reconstruction

Construction of a minesoil can be accomplished by various methods depending on land use objectives, spoil quality, and quality of pre-mine soils (Figure 4.1). All these options have one purpose: to provide a suitable plant growth medium that will meet the end land use objectives. Naturally the option chosen is dependent upon site-specific conditions and properties of the materials.

Option 1, producing a final minesoil landscape from dumped spoil without grading or placing cover soil, can provide valuable wildlife habitat and microsite diversity. This procedure is used by Westar Mining near Sparwood B.C. on the tops of dumps in a Subalpine area to provide diverse wildlife habitat using spoil with high rock content. The relief provided by the hummocky topography protects seedlings in wind-exposed areas and provides higher levels of effective moisture in depressions, and control of water erosion. This can be critical to plant establishment in exposed areas (Lesko et al. 1975; Root 1976). Hiding and thermal cover for small mammals and ungulates is also enhanced considerably over levelled terrain (Thomas 1979; Green et al. 1985).

Option 2 involves grading spoil (but no topsoiling or subsoiling) to provide a reclaimed landscape with surface form and slope steepness that matches land use requirements. This procedure can be followed when: (1) spoil quality is satisfactory for the post-mine vegetation requirements; or (2) better quality materials are not available to cover the spoil.

Options 3 and 4 involve salvage and replacement of pre-mine soils in one lift (Option 3) or in two lifts (Option 4). These options are related to: (1) the quality of pre-mine soils that are to be conserved; (2) the quality of the spoil; (3) the end land use and desired level of capability; and (4) operational realities. Option 3 applies to areas where pre-mine soils are salvaged in one lift due to (a) shallow depth or (b) lack of significant quality difference with depth.

Option 4 applies to areas where either (a) pre-mine soils are salvaged in two lifts due to good quality "topsoil" layers and lesser quality subsoil layers (but still better quality than spoil), or (b) topsoil-quality materials are very limited and sufficient depth to develop a soil requires placing regolith or other material as a separate lift, or (c) spoils have adverse

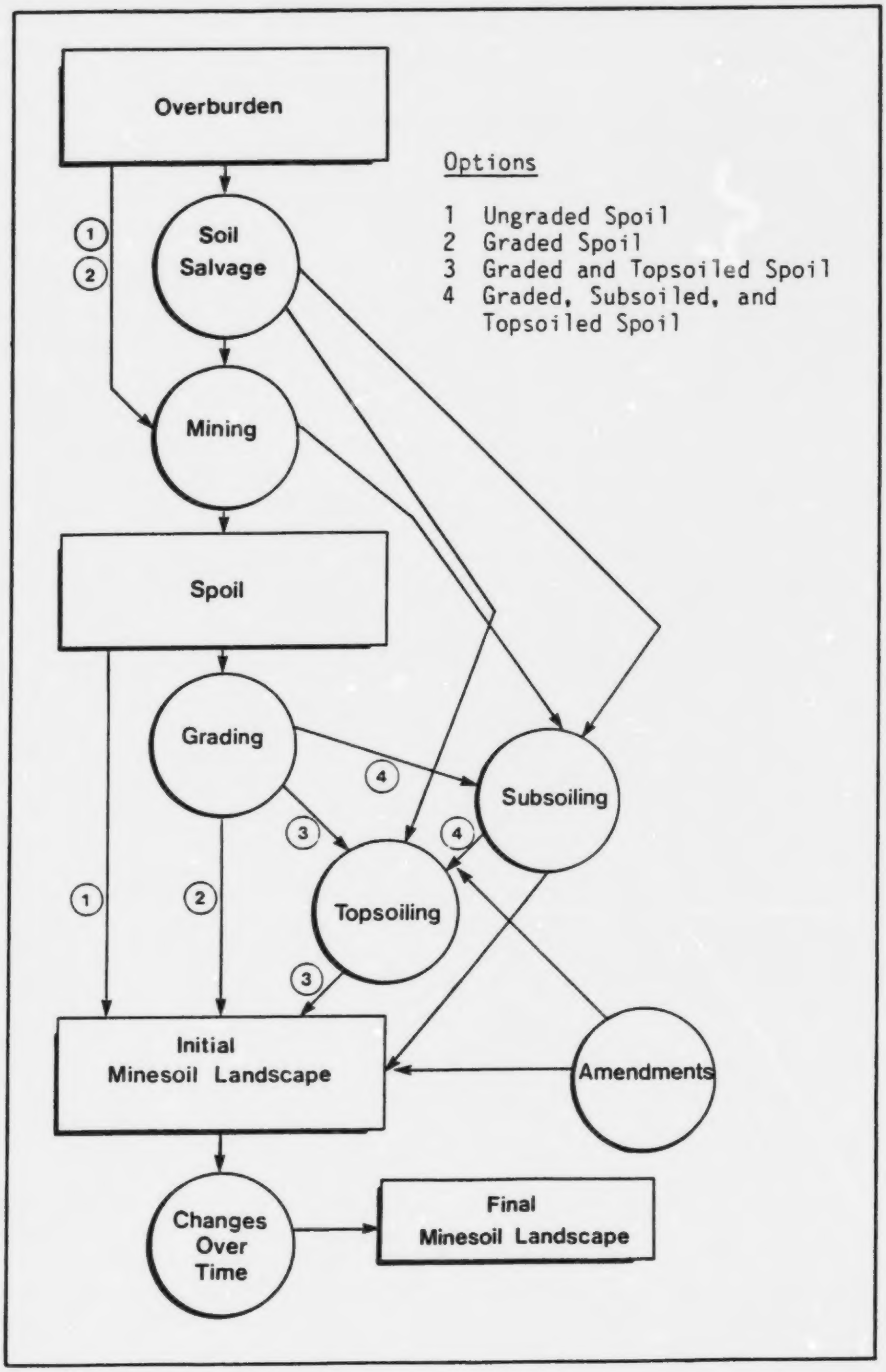
Overburden
Options
1 Ungraded Spoil
2 Graded Spoil
3 Graded and Topsoiled Spoil
4 Graded, Subsoiled, and Topsoiled Spoil
①
②
Soil Salvage
Mining
Spoil
Grading
④
Subsoiling
③
④
①
②
Topsoiling
③
Initial Minesoil Landscape
Amendments
Changes Over Time
Final Minesoil Landscape

Figure 4.1 Minesoil construction options.

characteristics requiring a substantial depth of cover (unlikely in the Mountain-Foothills Region), with salvaged soil or regolith or better quality bedrock spoil, which is then covered with "topsoil". Topsoiling can also be done by different methods including direct placement, placement from storage, supplemental top-dressing, and placement of "topsoil islands".

4.1.2 Soil Salvage and Replacement

There are two major reasons to salvage and replace surface soil materials:

1. To conserve pre-mine soil horizons, which can be a valuable resource; and

2. To provide for, or improve the quality of, post-mining soil landscapes that will support plant growth.

The questions that arise regarding the minimum quality of soil that should be salvaged, the number of lifts required, the total depth, and the replacement depth required cannot be answered simply or generally, but must be related to the reasons for salvage and replacement.

If the objective of a reclamation plan is to conserve favorable quality pre-mine soils, then the amount that is salvaged must relate to the quality and quantity of those soils. If the objective is to provide a specified land use potential (or capability), then landforms and soils must be developed that meet site and vegetation requirements to satisfy that land use. This requires specifications for landform and vegetation requirements in addition to information on the quality of pre-mine soils and spoil materials.

To evaluate the quality requirements (including the soil depth variable) of minesoils, the use of a holistic approach that considers the minesoil landscape as an ecosystem is suggested. This can be accomplished by evaluating the interactive effects of climate, topography, soil, and vegetation in terms of four effective properties:

1. Rooting medium;
2. Supply of moisture;
3. Supply of nutrients; and
4. Other limiting conditions.

The minesoil landscape requirements can then be designed on a site-by-site basis, using benchmark data to guide "levels of quality" to provide equal capability or productivity.

4.1.3 Horizon Reconstruction

It is apparent that over time minesoils will have more than one "functional depth interval" or horizon. The uppermost 15 to 20 cm (Horizon I) serves as a seedbed for plants and will be the active layer for the soil biological functions. The second (Horizon II) will be the deep rooting zone and the zone of maximum moisture storage (essentially the soil moisture control section). Deep rooting plant species can tap this deeper layer for moisture and possible nutrient uptake. The actual depths and quality requirements of each of these horizons varies with ecoregion and site, and the function of effective properties and requirements of vegetation.

A rationale for determining the minimum requirements of each of these horizons must recognize several variables. The appropriate pre-mine benchmark ecosystem can be used to establish guidelines for the minesoil, and these soils should be constructed or managed to provide similar functional characteristics to the pre-mine condition.

The recognition of horizons does not suggest that a separate lift of soil materials has to be placed to develop each horizon. The surface spoil material may be of suitable quality to serve as Horizon II, or as Horizon I if the management plan is to build up the organic matter content by growing grass-legume mixtures. In other cases, it may be necessary or desirable to use one or two lifts of coversoil to top-dress a spoil to develop the I and II horizons.

4.2 SOIL RECONSTRUCTION SITE FACTORS

There are many combinations of climatic, soil, vegetation and site treatment variables which affect a site. Some of the more important specific variables are: temperature, moisture supply, radiant energy, composition of the atmosphere, soil structure and the composition of soil air, soil reaction, biotic factors, supply of mineral nutrient elements and the absence of growth-restricting substances (Tisdale et al. 1985). Satisfactory plant growth depends upon a favorable interaction of these variables, and if any one of them is out of balance with the others it can reduce or prevent plant growth.

One of the available diagnostic techniques is the evaluation of individual physical and chemical properties of soil materials. However, the quality of a site involves interactions among several landscape and soil features, and no general answers are to be found by evaluating soil texture, organic matter content, slope, or aspect individually, except perhaps for an individual site for which there is considerable empirical data. Also, many features are neither uniform nor continuous in their interactions and their effects on growth from landscape to landscape (Murray 1977).

An alternative technique is to focus on fewer "effective properties" (Stone 1984) which reflect the net effect of combinations of several individual properties. The effective properties control growth and rates of moisture and nutrient supply at the stand level. High quality sites are defined by having upper ranges of each of these effective properties. Low quality sites may have a great range in soil characteristics and plant growth, but one or more effective properties are minimal for growth, and do not respond to the management system in place.

The following four statements summarize the points made by Stone (1984) about site quality and effective properties:

1. The site must provide a suitable medium for root development and anchorage, with adequate aeration and drainage. An impermeable layer or a watertable at shallow depth may restrict root growth, or a high percentage of coarse fragments may reduce the effective soil volume exploited by the roots. Soil water content can seasonally impair root growth and function by being too wet or too dry.

2. The site must supply sufficient moisture to sustain a rate of photosynthesis and avoid severe stress during periods of drought. This can be provided in any of several ways. Either the upper soil horizons have high available water storage or the plant roots exploit a greater volume of soil or fractured rock having perhaps less storage per unit volume. Or, soil storage is supplemented by access to a watertable, by saturated or unsaturated slope flow, or by run-on surface water. Topographic effects can reduce or increase evaporative demand, rendering the storage less or more effective.

3. The site must provide nitrogen and each of the mineral nutrients at rates sufficient to meet the needs of rapidly growing stands, together with any losses or diversion to temporary or permanent sinks. Ample nutrients can also be provided in several ways, some of which are not revealed by the usual soil analyses. High concentrations of nutrients and rapid turnover of plant litter, fixation of atmospheric N by legumes, exploitation of large soil volumes, and exogenous contributions by groundwater or run-on water can all contribute to nutrient supply.

4. The site must provide effective freedom from soil or climatically related adversities.

4.2.1 Climate

Climate is a predominant factor in the Mountain-Foothills Area with respect to plant growth and soil development (Holland and Coen 1982; Peterson and Etter 1970; Pettapiece 1970). The influence of climate has usually been evaluated at macroscale levels (Lieth 1974), but there is increasing evidence that relationships between the soil-plant system and radiation, temperature, humidity, precipitation, and wind must also be examined at mesoscale and microscale levels (Grossnickle and Reid 1984a,b; Larson 1980). An individual tree can respond to its own microclimate, which can differ from that of nearby trees (Mitchell 1967). The meso- and microscale climatic influences can be managed to various degrees by manipulation of site conditions during reclamation. Some of the key factors that can be modified are listed in Table 4.1.

While there have been no long-term studies of microclimate on mine spoils in the area, short-term studies have been made by Harrison (1974), Headdon (1980), Lesko et al. (1975), and Root (1973). All of these studies were conducted on abandoned mine spoils that pre-date reclamation efforts.

In summary, these short-term microclimate studies suggest that revegetation of coal mines in the Mountain-Foothills Area can be limited by high surface temperatures, low soil water availability, and high wind speeds, and that the limiting factors differ both within and between mine sites. To counter these conditions it is essential to try to match the plant species being used to the specific site.

It is recognized that these studies were conducted on old mine spoils that did not have the benefit of modern reclamation efforts that modify many of the adverse effects.

4.2.2 Soil Temperature

The vegetational changes that occur along an elevational gradient are due primarily to temperature (Billings 1979; Daubenmire 1943). Reclamation difficulty also follows the elevational gradient, becoming progressively greater with increasing elevation because of the harsh climate, lack of how-to information, and lack of adapted plant materials (Brown and Johnston 1979).

Temperature, and in particular soil temperature, becomes a limiting factor for plant growth as the elevation increases in the foothills and mountains. Revegetation methods that mitigate low soil

Table 4.1 Climatic factors that can be modified by site manipulation.[a]

Insolation and Radiation Factors

- Albedo of the soil surface and amount of heat absorbed
- Warming of soil and increase of microbial activity
- Ratio of radiation and aridity index

Precipitation Factors

- Moisture levels for a given radiation balance
- Moisture availability during growing season
- Snow cover for winter insulation of shrubs
- Length of growing season as a result of late snow cover
- Spring soil moisture as a result of snow accumulation patterns
- Snow and ice damage to trees

Air and Wind Factors

- Abrasion to trees by wind-borne snow, ice, and sand
- Exposure to winds that cause windthrow in trees
- Advection of cold air masses
- Changes to respiration rates without accompanying change in photosynthesis

---

[a] Information inferred from Peterson et al. 1982.

temperatures will be most successful in this region. Such methods include: (1) techniques that create microsites to maximize soil temperature and (2) selection of plant species tolerant of low soil temperatures.

Soil temperature also affects the ability of plants to absorb water and nutrients. Ehler (1963) showed that low root temperature can cause a water deficit and wilting of alfalfa even though the water supply is not limiting. Anderson and McNaughton (1973) examined 17 diverse native plant populations along an elevational gradient between 10 and 3170 m. Plants from low elevations were not able to maintain leaf water contents at a low soil temperature (3°C). Chapin and Chapin (1981) examined the adaptation of Carex spp. along a latitudinal gradient and found growth and phosphorus absorption at low soil temperatures was highest for arctic species. They also noted that cold soil adapted species had the highest root/shoot ratios and the smallest tiller mass.

Low soil temperature also affects soil micro-organisms. Colonization and biochemical processes such as organic matter metabolism are governed by soil temperature (Harris et al. 1966).

Soil temperatures are most commonly modified by mulches, but they can also be influenced by soil moisture content and surface roughness.

While an organic mulch lowers the soil temperature beneath it, the surface of the mulch is warmer during the day and cooler at night than the unmulched soil surface. Conditions of extreme temperature variation can cause serious injury to young trees and shrubs. Cochrane (1969) detailed methods to reduce heat and frost injury caused by subjecting young tree seedling transplants to extreme surface temperature variations. Steps include: (1) compact the soil around the base of the tree to reduce soil-air space and to increase the heat capacity; (2) remove litter from around the base of the tree and expose mineral soil; (3) mulch with a material that has a higher heat capacity than the soil (i.e., rock, gravel); and (4) maintain soil moisture by irrigation or planting in depressions.

Soil moisture has a pronounced effect on the heat capacity of soil. Because water itself has a high heat capacity, wet soils will also absorb and hold heat. Revegetation methods that maintain soil moisture will also maximize soil temperature. Organic mulches can increase soil moisture for a time, but can also be counter-productive when the soil dries or if soil temperature is lowered to a level that limits growth. Surface treatments that concentrate rainfall will increase soil moisture and subsequently contribute to maintaining soil temperature. Examples include contour furrows, dozer basins, pits, and gouges.

4.2.3 Evapotranspiration

Evapotranspiration is the net upward transport of water vapor (evaporation) from plant community and soil surfaces (Slatyer 1967). Research on evapotranspiration in the area has been done primarily in forested watersheds, such as Marmot Basin and Tricreeks, and may have little relevance to mine spoil areas. Root (1973) studied aspects of the water balance on the abandoned Cadomin (east) strip mine. The moisture deficiency was less pronounced and shorter in duration in the undisturbed natural areas adjacent to the mine site than on the mine site. Root (1973) attributed this to the higher wind speeds on the mine site. Therefore some additional site manipulation practices may be necessary to address the potential problem.

Thornwaite and Mather (1957) developed a simple procedure to estimate elements of the water balance from easily obtained climate and soils data. This method was used to calculate the potential evapotranspiration (PE) which is the evapotranspiration that would occur if water was not limiting, actual evapotranspiration (AE), moisture deficit (PE - AE), and moisture surplus (P - PE in months with average temperatures > - 1.0°C) for selected climate stations. The purpose was to show general trends in moisture deficiency. If the data were available, this method could also be used to calculate components of the water balance on mine sites, as was done by Monenco (1983) for oil sands tailings in the Fort McMurray Region.

4.2.4 Topography

The topographic requirements of post-mine lands can be considered first in terms of pre-mine and adjacent landscapes. The shape and geological structure of the land strongly influence the mining methods and shape and location of pits and spoil piles; and set limits for the final land shape that will be compatible with surrounding patterns and land use requirements. Acceptable landscape pattern and slope limits therefore vary from the Western Alberta Plains to the Foothills and Mountains, and by land use requirement. Landscapes should be aesthetically pleasing (at least not displeasing), especially in alpine and subalpine areas, and in all areas of high visibility. This is the major criteria applied by the majority of the public.

The topography of a landscape exerts considerable control over land use (Alta. ENR 1979), soil development (Dumanski et al. 1972), water movement (Gerrard 1981), water erosion (Wischmeier and Smith 1978), climate at meso and micro scales (Geiger 1965; Harrison 1977), natural vegetation patterns and forest productivity (Corns 1978; Dumanski et al. 1973; Spurr and Barnes 1980), and wildlife habitat values (Thomas 1979). Specific landscape requirements must be determined on a site-by-site basis.

Commercial forestry and watershed protection and land uses benefit from reduced slope angles. Wildlife habitat value for many species benefits from steep slopes, relief, and a diversity of landform and pattern (Green et al. 1985).

4.2.5 Soil Water

Water is essential to all physical, chemical, and biological processes in the soil, and is a dynamic property (Childs 1969; Klute 1973; Nielson et al. 1972). Productivity of trees and other plants in Boreal and Subalpine areas has been shown to correlate strongly to climatic, topographic, and edaphic variables that influence the availability of water (Corns 1978; Day 1964; Dumanski et al. 1973; Holland and Corns 1980; MacLean 1977; McMinn 1960; Monenco Consultants 1983).

The amount of soil water available for plant growth is related to: (1) the amount received at the site; (2) the amount that infiltrates the soil; (3) the amount that is stored; and (4) the amount that is available for plant growth (Wollenhaupt and Richardson 1983).

4.2.5.1 Amount Received

The amount of water received at a site is a function of precipitation and landscape characteristics. The amount of water that enters the soil is controlled by surface roughness and infiltration rates (Bussler et al. 1984; Childs 1969; Farmer and Richardson 1976; Hillel 1971). Soil moisture content is also a factor in partitioning water income into run-off, deep percolation, and storage. The soil surface must be porous to permit rapid infiltration. Total porosity and pore-size distribution depend on soil texture and structure, and structure can change with moisture content if soil aggregates are not water-stable. Soils that lose structure by puddling can form hard crusts upon drying that essentially prevent infiltration. Compaction of soils has considerable impact on pore-size distribution, and especially on loss of macro-porosity (Froehlich and McNabb 1984), resulting in decreased infiltration.

Carter and Doll (1983) found that moisture levels in North Dakota minesoils may be more dependent on topographic location than on soil materials, and that approximately two years elapsed before average available water levels approached those in undisturbed areas. Reconstructed soils on till at Obed Mountain had higher water content two and three years after construction than did reference soils (Obed Mountain Coal Co. 1984).

The infiltration and redistribution of water in minesoils often deviates from a slow, uniform downward flux due the presence of rock fragments, boulders, channels, and varying amounts of compaction. Flows may occur along fissures or may be impeded by discontinuities of pore size, with the result that parts of the profile may not be wetted (Rogowski and Weinrich 1981).

4.2.5.2 Infiltration and Movement

Moisture levels have been monitored in minesoils in North Dakota for several years (Schroeder and Bauer 1982). Results indicated that increases in soil moisture never equal precipitation minus plant use and evaporation losses, which led the authors to suggest that losses due to surface run-off were occurring (Doll et al. 1983). In a Montana study, moisture levels in some minesoils were similar to nearby undisturbed soils, but plants were not able to use the water due to poor soil structure and limited plant root development (Doll et al. 1983).

Bussler et al. (1984) reported unfavorable physical properties for forest growth in minesoils in Indiana. The minesoils generally had higher bulk density, lower porosity, lower permeability, higher coarse fragment and clay content, and lower available water-holding capacity than reference soils at comparable depths. Physical properties were related to the types of materials placed in the rooting zone and the machinery used for placement and grading. Limited porosity adversely affected aeration and water retention. Low capillary porosity partially reduced water-holding capacity in topsoil. Low non-capillary porosity near the surface of minesoils restricted water infiltration and percolation, thus causing surface ponding in small depressional areas (Bussler et al. 1984). The minesoils had favorable chemical properties, but were limited by physical characteristics.

Bouma and Anderson (1973) investigated the effects of texture and structure on water retention and water movement in puddled mixtures of sand and clay-sized particles of varying proportions and in pedogenic soil materials. They demonstrated that soil texture and structure resulting from mixing various-sized particles affect pore size, which has a considerable effect on moisture retention and movement at various levels of tension. The effects of increasing the content of fines in the sand-clay mixture were: (1) decreased saturated hydraulic conductivity due to smaller pore size; (2) a slower decrease of unsaturated hydraulic conductivity with increasing soil moisture tension; and (3) increased moisture retention and less rapid desorption of water at increasing tensions.

4.2.5.3 Water Retention

Water rentention in a soil is affected by the physical characteristics of the wetted part of the profile, including texture, structure (including porosity), organic matter content, and horizonation - or presence of discontinuities (Bouma and Anderson 1973; DeJong et al. 1983). Their studies indicated that soil texture is the main soil property influencing the water retention curves of disturbed mineral soils. Organic matter increased the water content at which a break in the retention curve occurred, but had little effect on the rate of release of water or the soil suction at which the water became more difficult to desorb. DeJong et al. (1983) pointed out that the amount of water retained at low soil tension depends primarily on pore-size distribution, which in turn depends on texture and structure.

Arkley (1981) measured moisture depletion to depths in excess of 274 cm from coarse loamy and sandy skeletal soils under mixed coniferous forests. Moisture depletion occurred in upper soil horizons in the early part of the growing season, but from deeper layers in July and August. Tree species differ in their response to moisture regime. Pine species can tolerate low soil water levels by forming deep root systems and have the ability to form long lateral roots close to the surface to avoid a high watertable or other restricting layer (Mueller-Dombois 1974), but pine cannot withstand flood conditions. Mueller-Dombois demonstrated that jack pine root development was also affected by soil texture, being better in loamy sand than in sand-textured soil based on better nutrition and more vigorous plants.

White spruce growth is affected more strongly by residual water held in the upper soil profile than is pine or black spruce (Mueller-Dombois 1974). This relates to its distribution in boreal forests where its best growth is on soils with fine textures and strongly developed Bt horizons or groundwater seepage (Lesko and Lindsay 1973:; Mueller-Dombois 1974). Under experimental conditions, white spruce growth peaked when the watertable was at 110 to 130 cm in loamy sand soil and at 130 to 150 cm in sand (Mueller-Dombois 1974).

Monenco Consultants (1983), in their Alberta oil sands report, recommended an available water capacity of 15 percent in the 0 to 15 cm soil layer and 7.5 percent for the underlying material for jack pine. Their recommendation for a mixedwood stand of aspen and white spruce was for 15 percent AWC for the 0 to 15 cm depth, 10 percent AWC for the 15 to 50 cm depth, and 7.5 percent AWC for the 50+ cm depth. For grasslands the values were 15 percent AWC in the 0 to 30 cm depth and 7.5 percent AWC for 30+ cm.

An interpretation of the literature by Union Oil Company Ltd. (1981) concluded that an AWC of 6 to 10 percent was required to grow pine or white spruce in the Boreal Uplands. Russell (1980) reported that 6 percent AWC for the 0 to 20 cm depth was correlated with reasonable growth on spoils at Mountain Park, which is in the subalpine zone.

4.2.4.4 Soil Moisture Control Section (SMCS)

By identifying the SMCS (as defined by Soil Survey Staff, 1975 USDA) of pre-mine soils, an appreciation of the soil depth interval important for moisture storage and supply in the natural system is gained. Development of a similar SMCS in a minesoil, within a similar moisture regime, should indicate similar soil water-plant relationships in the post-mine environment (assuming equal effects of other variables).

The water requirements of reclamation communities are not known, and estimates of them have low confidence levels.

In concluding this discussion on soil water it is important to understand that soil moisture has a direct influence on the growth of plants and that it also influences soil temperature, aeration, microbiological activity, availability of nutrients, and also the concentration of toxic substances.

4.3 ROOTING MEDIUM FACTORS

4.3.1 Quality

The quality of soil as a physical rooting medium can be thought of as a function of several factors. Soil structure, porosity, bulk density, strength, temperature, and coarse fragment content strongly influence root development, aeration and drainage, water storage, and anchorage (Taylor et al. 1972). Soil reaction, salinity, nutrient status, and microbial activity primarily affect nutrient and water uptake by roots but also influence root growth rates and root-shoot ratios. An illustration of the soil variables that interact to affect the quality of the soil as a rooting medium is presented in Table 4.2. The characteristics of the plant determine requirements and tolerance for stress and general root growth pattern. Climatic factors at the microscale level greatly influence soil moisture and temperature relationships. Topographic factors influence soil moisture, soil temperature, and physical stability processes.

Table 4.2. Summary of soil variables that interact to influence the effective properties of a site.

EFFECTIVE PROPERTIES / INTERACTING SOIL VARIABLES	Structure	Pore-Size Distribution	Air-Filled Porosity	Avail. Water Capacity	Bulk Density	Depth to Restricting Layer	pH	Organic Matter	CEC	Soluble Salt Content	Sodium Content	Soil Temperature	Heat Flux	Particle Size Distribution	Coarse Frag. Content	Microbial Activity
1. ROOTING MEDIUM																
Root Development	*	*			*	*	?			*						
Aeration and Drainage	*	*	*		*	*					*					
Water Storage	*	*		*	*	*		*						*	*	
Nutrient Uptake		*					?			*		*				*
Anchorage	*				*	*								*	*	
2. NUTRIENT POOL AND SUPPLY																
Status (availability)							*		*			*				
Amount Available (capacity)						*		*	*			*				*
Transport		*			*	*				*	*					
3. WATER STORAGE AND SUPPLY																
a) Surface Soil Water																
Soil Detachment	*							*						*		
Crust Formation	*	*		*	*			*		*	*			*		
Water Content and Retention	*	*		*	*			*		*	*	*	*	*	*	
Infiltration	*	*	*		*			*		*	*			*	*	
b) Subsurface Soil Water																
Retention and Desorption	*	*		*	*	*		*			*	*	*	*	*	
Perviousness	*	*			*	*		*			*			*	*	
4. LIMITING CONDITIONS																
a) Adverse Soil Conditions							*			*	*					
b) Climatic Exposure												*	*			

4.3.2 Physical Parameters

4.3.2.1 Organic Matter

Soil organic matter is obviously important in its impact on mineral colloids and plant nutrition, however it is also important in its physical influence on soils. As Wilde (1958) points out, organic matter exerts beneficial effects on soil structure, porosity, permeability, and aeration. Organic matter also increases the water-retaining capacity of soil; however, this does not necessarily mean more water is available to plants. As reported by Feustel and Byers (1930), some organic materials, especially peat, hold water so tightly that it is not available to plants. Therefore, some of the current practices of incorporating organic matter into mineral surface soil may not be as beneficial as some believe them to be for increasing available soil moisture.

A minimum organic matter level of 2 to 4 percent is desirable even in the sandiest soils (Pritchard 1979). Wilde et al. (1965) recommend a minimum organic matter content of 1 percent for planting jack pine and 3.5 percent for planting white spruce. Jack pine is presented here because it is similar in many ways to lodgepole pine. Wilde (1958) recommended 0.7 percent organic matter content for lodgepole pine.

Despite the importance of soil organic matter, it is wrong to assume that organic matter is absolutely essential to tree growth. (Wilde et. al, 1965) found that trees can grow quite well on a raw geological matrix, provided that the tree seedlings have been inoculated with mycorrhizae and that there is an adequate supply of water and nutrient-bearing minerals. Pritchard (1979) reports that not only do tree roots provide support and account for absorption and transport of nutrients and water, but they also assist in controlling erosion and mass soil movement, and make a considerable contribution to soil organic matter.

Organic matter levels can be re-established in two ways. One method is to salvage the material prior to mining and use it mixed or otherwise as a cover material. The other method is to use the biological system to build it up to "acceptable" limits.

4.3.2.2 Porosity

Adequate root development of seedlings and larger plants in mineral soils requires an open network of interconnecting voids (Stolzy and Barley 1968).

Coarse textured soils normally have less pore space than fine textured soils; however, the pores are larger in coarse textured soils. Porosity is important as it determines the amount of relative space available for water and air. Sufficient aeration and drainage must be provided to restore aerobic conditions after heavy rains, as many plants begin to die after 24 hours of waterlogging (Van't Woudt and Hagen 1957).

Adequate total porosity and the presence of interconnected pores are required to provide oxygen to the entire root system. Under conditions of very low oxygen concentrations, micro-organisms produce ethylene, which restricts root growth (Dowdell et al. 1972) and makes soil nitrogen unavailable to plants through the anaerobic process of denitrification.

Aeration effects on the seed, seedling, and root system can regulate growth and yield, depending on the stress undergone by the plant under the conditions regulating the total environment and the particular needs of the plant.

Vomocil and Flocker (1961) described an ideal root bed as a soil with 50 percent of the soil volume occupied by solids, 25 percent by water, and 25 percent by air when the soil has reached equilibrium in drainage after wetting. Undisturbed forest soil porosity ranges from 30 to 65 percent (Wilde 1958). A porosity index can be calculated from the pore-size distribution and related to how well aeration is provided for (Cary and Hayden 1973). Pore-size distribution is a dynamic soil property and surface traffic, tillage, root growth, soil fauna, wetting and drying, and freezing and thawing continually rearrange the pores.

4.3.2.3 Texture

Soil texture is composed of two important fractions: a coarse fraction and a fine fraction.

Texture is important because it has a strong influence on moisture retention; the more fines, the greater the water retention. Too many fines can cause problems with soil aeration, therefore in reclamation efforts attention must be paid to not getting too high a content of fines.

Monenco (1983) recommended a minimum silt plus clay content of 25 percent for a jack pine stand, 20 percent for a grassland on a dyke slope, and 30 percent for a mixedwood stand of primarily white spruce and aspen. These values are for the surface 15 cm.

Wilde et al. (1965) reported that jack pine stands in Wisconsin had average silt plus clay percentages of 7, 9, and 10 percent for low, medium, and good sites respectively. The average values for white spruce silt plus clay were 12, 37, and 44 percent for low, medium, and good sites respectively. The values for 22 stands of medium site quality white spruce silt plus clay content ranged from a low of 10 percent to a high of 59 percent. Wilde (1958) recommended 5 percent as the minimum silt plus clay for lodgepole pine.

4.3.2.4 Bulk Density

Soil bulk density has been shown to correlate to reduced productivity, but there is not a simple cause-and-effect relationship between bulk density and productivity (Froehlich and McNabb 1984). Bulk density (volume weight) values are affected by particle density in addition to content of voids. Compaction causes greater relative change in pore-size distribution than in bulk density or total porosity (Vomocil and Flocker 1961). The adverse influence of compaction on plant growth is due to effects on soil moisture, soil air, soil temperature, and impediment to root growth and shoot emergence (Barnes et al. 1971; Gill 1961; Phillips and Kirkham 1962).

Minore et al. (1969) tested effects of high soil density on seedling root growth of several tree species. All species evaluated grew through a sandy loam soil with bulk density of 1.32g/cm^3. Lodgepole pine, Douglas-fir and red alder grew entirely through density cores of 1.45 g/cm^3 while Sitka spruce, Western red cedar, and Western hemlock did not penetrate. Mitchell et al (1981) found loblolly pine seedling root system absorbing capacity decreased at bulk densities above 1.4 g/cm^3 in fine sandy loam soil. Mirreh and Ketcheson (1972) demonstrated that soil resistance to root growth would be poorly predicted unless simultaneously related to bulk density and matrix pressure variables. Armson (1980) recommended a maximum bulk density of 1.2 g/cm^3 in the surface soil layer to encourage root growth of young plants. Veihmeyer and Hendrickson (1948) stated that compacted layers of sand with a bulk density of 1.75 g/cm^3 or clay layers with a bulk density of 1.55 g/cm^3 may prevent the penetration of roots.

The maximum bulk densities recommended by Monenco (1983) were less than 1.3 g/cm^3 for the surface 15 cm of soils. A bulk density of less than 1.5 g/cm^3 was recommended for the 15 to 50 cm horizon of the mixed wood community.

Bulk density values of 1.43 to 1.49 g/cm^3 were reported at a depth of 38 cm by Fedkenheuer (1980) for pure tailings sand underlying a mixed layer of peat and tailings sand averaging 20 to 25 cm in thickness. Grass and legume roots were found extending down to an average of 38 to 48 cm. Lower bulk densities were noted in the upper profiles.

In summary, the literature and the benchmark communities appear to indicate that the bulk density values presented by Monenco (1983) for the oil sands of northeastern Alberta are too conservative for the Mountain-Foothills region. This is particularly true when stones or rock fragments are present as they tend to modify the effects of bulk density and compaction.

4.3.2.5 Rock Fragments

Stoniness is not a direct limitation to growth (Knight 1967), and excessive amounts of stones do not significantly affect pine productivity (Dumanski et al. 1973). As stated by Knight et al. (1966), it is expected that stoniness will be used seldom, if at all, as a limiting factor in assessing the capability of land for forestry. Berg and Barrau (1978) found the presence of coarse fragments could enhance plant moisture conditions by reducing run-off and evaporation loss in certain cases. There was also a beneficial effect for deep-rooted plants, in that the presence of coarse fragments made it easier for roots to find channels to follow.

Ashby et al. (1984) concluded that minesoils with a higher coarse fragment content (>2 mm) may have productivity equal to or higher than pre-mine soils. Smith et al. (1976) reported that productivity was not seriously reduced by up to 75 percent coarse fragments by weight in minesoil top and subsoil horizons. In addition, these soils were only slightly erodible, while topsoil was considerably more erodible. Nishimura (1974) cautioned against placing more than 15 cm of soil on a fill or steep cut slope because of the possibility of soil slumping. He suggested adding 10 to 15 cm of topsoil and roughening the subsoil before applying the topsoil to "bond" the two together to minimize slumping.

Ashby et al. (1984) reported that the volume of fine earth available for root growth may not be decreased by stones and that in actual practice, increased rooting depth on loose minesoils seems to more than compensate for any loss in soil volume caused by stones. They also quoted numerous studies that have demonstrated as good, and in many cases better, forage yields on stony minesoils compared to off-mine undisturbed soils.

As Ashby et al. (1984) stated, a high degree of association between stony soils and successful tree growth is clear. This is most likely due to the long life, conservative nutrient economy, relatively coarse root systems, and close association with mycorrhizal fungi which trees have. Kolar et al. (1981) reported that in southern Illinois trees had larger root systems and better growth on ungraded, rocky cast overburden than on graded overburden with topsoil applied. The rooting depth for three oaks was from 35 to 47 percent deeper in the ungraded rocky material than in topsoiled overburden. It was felt that free water held between and under stones is a factor that may have been underestimated as another advantage to having stones present in soils (Ashby et al. 1984).

In summary, it is definitely not necessary to have rock-free soil material to grow grass for grazing, shrubs for wildlife habitat, or forests for harvesting. There is also some indication that topsoiling is not necessary, or should be limited in thickness applied to minimize soil erosion or slumping.

4.3.3 Depth Requirements

4.3.3.1 Grasses and Legumes

The actual requirements and tolerance limits of native and agronomic grass species on reconstructed soils are not well known (Watson et al. 1980). Considerable research has, however, been conducted in the Northern Great Plains (U.S.) Region on the effects of soil depth on the productivity of grasses. Biondini and Redente (1983) observed bunchgrasses to be more responsive to increased topsoil depth than rhizomatous grasses in Wyoming. Redente et al. (1983) and Redente et al. (1982) noted forb productivity was highest on the shallowest topsoil depth evaluated. Grass productivity increased to a certain topsoil depth, but shrub productivity continued to increase with increasing depth.

Barth (1984) found that, generally, a soil layer (A, B, and partial C horizons) 50 cm thick was required to maximize grass production over sodic spoil. However, he reported that in some of these situations only 6 cm was required to maximize production, and in some others, more than 50 cm depressed productivity. In his opinion wheatgrass generally requires 40 to 50 cm of soil over sodic spoil, while green needlegrass requires about 70 cm. He also reported that 14 cm of soil over sodic spoil was required to optimize microbial activity.

Pinchak et al. (1985) compared crimped straw and standing barley stubble with non-topsoiled plots to improve seeded grass growth. They found that 40 cm of topsoil was required to show a difference and also to minimize the biomass of invading non-seeded annual and biennial forbs. Twenty centimetres did not significantly improve biomass production of seeded species, but there was a higher biomass of invading species. It would appear that the lesser amount is desirable if one is attempting to encourage native species invasion. A field study in northwest Colorado found that the thickness of topsoil directly increased growth up to the maximum of 46 cm used in the project (McGinnies and Nicholas 1980). However, these depths of topsoil are much greater than exist on premine soils in the Mountain-Foothills region.

Legumes (and many grasses and forbs) are capable of deep rooting, which may be important for drought tolerance. Minesoils, however, seldom restrict deep rooting unless compacted layers are present, and root mass is usually concentrated within 20 cm of the surface. Lauenroth and Whitman (1977) found that 70 percent of root biomass occurred in the upper 15 cm in mixedgrass prairie. Dahlman and Kucera (1965) reported that over 80 percent of root mass was in the upper 25 cm in tallgrass prairie. Lauenroth et al. (1975) found that 85 to 90 percent of roots occurred in the upper 20 cm in mixed prairie grassland.

Fedkenheuer (1980) reported that, after two and one-half growing seasons in the northeastern Alberta oil sands, grass and legume rooting depths ranged from 33 to 51 cm, with approximately 85 percent of the roots in the upper 25 cm of material. Rowell (1978), also working in the oil sands, reported that the majority of grass and legume roots in his study were in the upper 15 cm of material.

Results of vegetation and soil depth trials in the Smoky River Coalfield (in the Upper Subalpine ecoregion) reported by Macyk (1984a) and Macyk and Widtman (1983) are a primary information source. They state that 15 cm of soil over spoil is adequate for revegetation utilizing grasses and legumes (provided that nutrient levels are maintained and moisture is adequate). They also report that grasses will establish in spoil that is not topdressed with soil. In their studies, the suitability of the spoil was related primarily to the proportions of fines and coarse fragments.

Macyk (1983) reported that grass roots extended down to the maximum of 10 cm in soil and 18 cm in ash substrate. Legume roots extended to a maximum depth of 30 cm in ash, and down to 50 cm in the soil substrate. He also stated that a soil layer (or cap) in excess of 15 to 30 cm in thickness will not result in significant uptake of phytotoxic elements or those hazardous to animals. In other words, a 15 to 30 cm covering of soil over ash is all that is required to minimize plant uptake of undesirable elements.

Carrying this one step further, it would seem that if this is the case for ash, which contains toxic elements, there certainly should not be a need for any thicker a covering over the typical spoil of the Mountain-Foothills region. The spoil does not contain any known undesirable elements. Perhaps a judicious mix of the appropriate grass and legume species would do very well without cover soil given the climate and spoil conditions in the Mountain-Foothills region.

4.3.3.2 Woody Plants

No information was found to indicate minimum rooting depth requirements or root distribution patterns of specific shrubs. For the purposes of this report, the information regarding forest communities is interpreted to be the maximum required for shrubs associated with the respective forest stands.

Soil depth for woody plants is important in two major ways: (1) sufficient soil volume for root growth and mechanical support must be available, and (2) sufficient soil volume to provide an adequate water supply must be present. These requirements vary with site characteristics (slope position, aspect) and soil texture and coarse fragment content. Dumanski et al. (1973) found little relation between productivity and rooting depth, and found some very high growth rates on shallow soils. Eis (1970) noted greater lateral root growth in shallow soils, indicating the tree was adapting to the situation.

Krumlik (1980) noted that plant rooting depth was related to several factors, including soil depth, soil moisture regime, soil aeration, soil temperature regime, availability of plant nutrients in the soil profile, and characteristic root formation of different plant species. Holland and Corns (1980) commented that the combined result of inter-relationships among the many controlling variables is that other factors besides soil depth are important in controlling forest and other vegetation growth.

A concensus at the Alberta RRTAC Workshop on the Reconstruction of Forest Soils (Ziemkiewicz et al. 1980) was that there are too many factors influencing tree growth and tree rooting depth to identify soil depth requirements in reclaimed landscapes.

One of the reasons for the variability is related to the root systems themselves, since there are lateral roots as well as vertical roots, and woody plants rely on one or both to varying degrees. As pointed out by Eis (1970), there is considerable genetic control of root form. Vertical roots (for support and deep water use on xeric sites) are influenced by site conditions, and are less necessary on mesic sites (Horton 1958; Strong and LaRoi 1983b; USDA Forest Service Handbook 606).

Strong and LaRoi (1983b) reported that the root systems of most boreal trees are dominated by horizontally spreading lateral roots that absorb moisture and nutrients within 3 to 15 cm of the soil surface. Fedkenheuer (1969) found jack pine roots in Minnesota of common abundance down to 45 to 63 cm and occasional down to 68 to 188 cm depending upon soil type. Aspen-dominated stands had roots in the common category stopping at anywhere from 20 to 76 cm, with the roots stopping totally at 53 to 102 cm depending upon the stand.

When discussing rooting depth it is important to examine root density and not just look at total depth of rooting. As pointed out by Wilde (1958), the surface 15 cm is the most important portion of a forest soil. The root systems of most boreal trees are dominated by horizontally spreading lateral roots that absorb moisture and nutrients within 3 to 15 cm of the soil surface (Strong and LaRoi 1983b). Klock (1982) reported that the upper 3 cm of surface mineral forest soil had a marked effect on the potential site productivity of Douglas fir and a lesser effect on lodgepole pine. He attributed the latter to lodgepole's pioneer status in which it is capable of supporting itself under lower fertility regimes.

Identification of the "effective rooting depth" (the depth at which root abundance drops to few, Walmsley et al. 1980) in forest soils is only available for a few selected areas in the Boreal Uplands (Robertson et al. 1984) and other parts of Alberta (Holland and Coen 1982; Knapik and Westworth 1982). This depth is usually in the range of 40 to 50 cm and seldom exceeds 70 cm in the Boreal Uplands. These depths generally correspond to the depth of soil development. The depth of soil development or solum depth is an indication of the depth of active biological and soil processes and can be used as a proxy for rooting depth requirements. Average solum depths (depth to bottom of the B or BC horizon) for freely drained soils in the ecoregions of interest to this study are shown in Table 4.3.

Table 4.3. Typical solum depth of freely drained forest soils in the Mountain-Foothills Area

Ecoregion	Depth
Boreal Uplands	30 to 50 cm (some to 70 cm)
Montane	30 to 40 cm
Subalpine	30 cm

Strong and LaRoi (1983a) found aspen and jack pine roots extended to their maximum depth of 130 cm in sand in the Hondo-Lesser Slave Lake area of central Alberta. The minimum depth of rooting was found on organic soils. They reported that maximum root concentrations occurred in the LFH layer and the organic/mineral soil interface. For all of the 11 stands studied, the median root density occurred at 23 cm or less (for eight it was at 15 cm or less), with greater than 90 percent of all the root biomass estimated to occur within this near-surface rooting zone. The greater depths were found in the older stands (about 170 years for jack pine and aspen).

Lodgepole pine, jack pine and aspen are species that are adapted to establishing after fire. In one of the few tree root distribution studies in Alberta, Strong and LaRoi (1983b) noted that jack pine and aspen, which are pioneering species, had their lateral roots established in mineral soil horizons. White spruce and Subalpine fir, which are late seral species, had lateral root development in the organic surface layer. They related this to the fact that jack pine and aspen establish after forest fires, when the organic layer has been burned off, and the later seral species establish in older stands when a litter layer has built up. The major mass of tree roots in mature lodgepole pine and white spruce stands in Western Alberta occurs at the interface of the organic forest floor and the mineral soil (field observations by the authors). The relative importance of these tree roots to nutrient or water uptake at different depths is not known (Armson 1980).

Kimmins and Hawkes (1978) found 67 percent of white spruce - subalpine fir overstory fine roots in the upper 8.3 cm of the soil profile, specifically the LFH plus Ae horizons. At many of their sample sites the overstory fine roots were all in the top 28 cm of the soil profile (8.3 cm of LFH and Ae, plus the next 20 cm of mineral soil). They found slightly more (69 percent) of the understory fine roots in the 8.3 cm thick LFH plus Ae layer. At four of the sampling points all of the fine roots were found in the LFH, Ae and the next 10 cm of mineral soils for a total thickness of 18 cm. They reported that concentrations of macronutrients in fine roots tended to decrease with depth and that this reflects a greater uptake of nutrients from the more fertile LFH layer.

Eis (1970) studied rooting in white spruce, alpine fir and lodgepole pine between 5 and 15 years old. Sixty-five percent of the white spruce had all their roots found at less that 22 cm, while the remaining 35 percent of the spurce trees had roots penetrating down to as far as 38 cm. The average root penetration for alpine fir with a well-developed taproot was 26 cm with a maximum of 45 cm. Lodgepole pine had an average root penetration of 36 cm with a maximum of 62 cm. He also found that lateral roots became more prominent with increasing age. This appears to be consistent with several recent nutrient cycling studies which have also identified a shift in the zone of intensive rooting from the mineral soil to the detritus with increasing stand age, which follows a shift in the location of nitrogen (Gholz and Fisher 1984; Hamburg 1984).

Tree root distribution in a Balsam fir stand reported by Damman (1971) shows the dominance of roots in the forest litter layer and the correlation of soil development depth to total rooting depth (Table 4.4).

Table 4.4 Tree root distribution in a Balsam fir stand (after Damman 1971)

Soil Horizon	Portion of Total Mass of Tree Roots <1 cm
F + H	50%
Bt	25%
BC	17%
Total in Solum	92%

Macyk and Widtman (1983) compared root growth of approximately 10-year-old lodgepole pine and white spruce on reconstructed and natural soils in the Smoky River Coalfield and found no differences in root form. Roots were concentrated in the upper 30 cm of the soil with only minor rooting below 50 cm for both spruce and pine within the reclaimed and undisturbed areas (Macyk 1984a). Trees growing in dense grass cover had sparse rooting systems (which may relate to more available nutrients or to moisture conditions) compared to trees in less dense cover. Macyk (1984a) also reported better growth rates of pine and spruce on reconstructed soils than in natural forests, and better growth rates than on reforested clear-cut areas.

Grossnickle and Reid (1982) measured 30 to 40 percent of root development between 20 and 30 cm soil depth for lodgepole pine containerized seedlings grown for five years in a Subalpine forest in Colorado. Roots in container plugs may be restricted in growth due to outward movement of water from the plug to the soil, which has greater matrix forces (Day and Skoupy 1971).

It should be apparent from the preceding discussion of the literature that the surface 10 to 20 cm is the most important soil layer when attempting to reconstruct forest soils. This does not necessarily mean 10 to 20 cm of the original soil must be replaced. There are many spoil materials that appear suitable for use without topsoiling as long as they are nutritionally suitable. It is also important to note that depth of rooting in land capability classification for forestry in Alberta has not been used as a limitation (Knight, 1967). Topographic position and soil texture, with their influence on aeration, water holding capacity, drainage, and compaction are much more important parameters to be considered in developing a reclamation plan. Perhaps as a general approach, 15 to 20 cm of suitable soil material (see Table 4.8) should be present over 30 to 35 cm of spoil with Family Particle Size finer than fragmental (i.e., large voids are filled) and no restrictions that would cause ponding on sites at which conditions drier than subhygric are desired.

4.4 SOIL MICROFLORA AND FAUNA

A number of studies have demonstrated that soil microflora are important in plant nutrient availability and uptake either through mineral weathering or organic matter decomposition (Jurgensen 1978). Micro-organisms can influence the supply of essential growth factors and vitamins to plants and may also influence plant root morphology and root to shoot ratios (Barber 1968; Bowen and Rovira 1976; Nicholas 1965). Establishment of diverse, active populations requires the presence of organic matter (carbon) in the minesoil for an energy source; sufficient moisture; and nitrogen, sulphur, and favorable pH. The plant/micro-organism relationships of special concern for mine waste rehabilitation are mycorrhizae development, organic matter decomposition, nitrogen availability and transformations, and rhizosphere/spoil interactions.

4.4.1 Non-Mycorrhizal

Organic amendments added during minesoil construction help initial plant establishment, but play only a minor role in building a large, stable organic matter fraction (Jurgensen 1978). This role is played by the microflora and fauna that decompose the organic residue and release nutrients. The greatest potential for biological addition of nitrogen to minesoils is from the symbiotic association of N-fixing organisms and higher plants. For example, alfalfa can fix up to 200 kg $ha^{-1}yr^{-1}$ (Stewart 1966). Low levels of organic matter, soil moisture and nutrient deficits, and high or low soil temperatures inhibit growth, nodulation, and N-fixation. Few studies have actually measured the amounts of nitrogen fixed in minesoils. Dancer et al. (1977a, b) reported nitrogen gains from 5 to 125 kg $ha^{-1}yr^{-1}$ in kaolin minesoil colonized by native legumes. Forage legumes on fertilized and limed plots fixed much greater amounts of nitrogen than the native legumes. The most obvious solution to improve legume establishment and fixation is to alter site and soil conditions to favor development (Jurgensen 1978).

Fessenden (1979) reported that at least 49 actinorhizal (N-fixing non-legumes) plant species either had been or were being investigated for use in land reclamation in North America because of their pioneer plant properties and because they generally had low maintenance requirements. He stated that "the potential for management gains in this field is enormous; however, the work is time consuming and long term."

Visser et al. (1984a) reported that slender wheatgrass was much more effective in enhancing microbial activity and biomass carbon development than was white spruce. This was attributed to the more fibrous root system of slender wheatgrass compared to white spruce, as well as the greater productivity of the wheatgrass. Thus slender wheatgrass has the ability to "rapidly improve the microbially available C status of an impoverished soil by introducing large quantities of dead plant parts and exudates." This is a particularly important item for alpine and subalpine mine situations where soils are often shallow and lacking in available carbon.

Visser et al. (1984b) found that sewage sludge significantly improved spoil fertility and appeared to be acting as a slow release fertilizer, releasing nutrients over the longer term to the slender wheatgrass, alsike clover, white spruce, and willow utilized in the study. Alsike clover grew as well in the fertilizer treatment as it did in the sewage sludge. Apparently it was fixing nitrogen as required to compensate for leaching losses of nitrogen from the fertilizer treatment, which enabled it to do well regardless of the treatment.

Assessment of microbiological activities and effects on soil rehabilitation must be done on an individual site basis, and care must be taken when generalizing from site-specific information (Jurgensen 1973; Parkinson 1979). The current level of information limits our understanding of rates of establishment and roles under various minesoil conditions (Sims et al. 1984).

4.4.2 Mycorrhizal Fungi

Marx (1975) and Riffle and Boosalis (1979) state that mycorrhizal development is critical for the growth of trees and many other plants on spoils and natural soils. These associations increase nutrient and water absorption and hence nutrient cycling; feeder root health and longevity; and tolerance to drought, high soil temperatures, soil toxins, and extremes of soil pH (Marx 1980; Reid 1984).

The re-establishment of mycorrhizae after mining is a subject with which many questions are associated. Rives et al. (1980) found that storing topsoil at a North Dakota mine substantially reduced levels of viable vesicular arbuscular (VA) mycorrhizae. Diluting the topsoil resulted in about 8 to 10 times more viable propagules in the undisturbed soil than the stored topsoil.

Allen and Allen (1980) found that after two to three years mycorrhizal infection had increased up to 50 percent of undisturbed prairie levels in northeastern Wyoming on topsoil mixed with subsoil a common reclamation practice. They also reported that the recovery of VA mycorrhizae on disturbed areas appears to be influenced by a number of interactions. These include initial spore count, soil nutrients, soil texture, moisture, genotype of the plant host, plant cover, and the amount of time since reclamation was initiated. Plant cover (density) also may be important, since they found greater root infection on sites having denser cover. Root contact and intermingling has been found to result in a greater infection rate (Fitter 1977).

A greenhouse study by Danielson et al. (1983a, b) using peat, a clay overburden sample from a 2 m depth, a fine textured overburden/soil from the 0.1 to 0.7 m depth, and a coarse textured overburden/soil from the 0.1 to 0.7 m depth was conducted to evaluate mycorrhizal development and decomposition rates as well as to compare the effects of mixing peat and overburden to those obtained by stratifying but not mixing the materials. Results of the study indicate that it may be useful to separate the surface metre of overburden (which includes developed soil) from the material below it and to subsequently use this material as a source of VA mycorrhizal inoculum.

Zak et al. (1984) reported that the mycorrhizal status of a subalpine minespoil from the Cadomin-Luscar coalfield amended with fertilizer, feather moss peat, or sewage sludge did not change significantly between the second and fourth year. They also found that initial development of mycorrhizae was generally slow in the subalpine minespoil; however, the peat-amended spoil did give earlier VA mycorrhizal infections.

Mycorrhizal associations are not static, but Danielson et al. (1984) reported they persist for at least several years. Their research utilizing subalpine spoil revealed E-strain fungi were being replaced on white spruce after four years. The spread of fungi from plant to plant was found to be relatively slow. Mineral fertilizer did not have much effect on mycorrhizal development, while sewage sludge slowed mycorrhizal development.

4.5 PLANT NUTRIENTS

4.5.1 Nutrient Supply

The majority of nutrients taken up by plants enter the plant through the root system in water and perhaps directly via mycorrhizal associations (Wilde 1958). The amount of nutrients immediately available for uptake is a very small portion of the nutrients in the soil as the ions in solution are in equilibrium with those held in solid or nonactive forms (MacLean 1977)

Weathering of bedrock materials is also a source of nutrient supply. Soils, regolith, overburden, the material overlying coal strata are all disturbed and re-ordered during mining. Clayton (1979) states that the macronutrients supplied by bedrock weathering include phosphorus, potassium, calcium, and magnesium. Much of the sulphur also becomes available through this route. Iron, molybdenum, boron, copper, manganese, and zinc are also available from rock weathering. He also states that minerals weather at different rates depending on chemical composition and crystal structure. He goes on to point out that knowledge of the rate differences and an understanding of their causes is necessary if one is to successfully relate data on rock weathering and water and soil chemistry to nutrient gains in forest ecosystems.

4.5.1.1 Cation Exchange Capacity (CEC)

The CEC of a soil is mostly due to the clay and silt fractions as well as the organic matter. Cation exchange capacity provides an indication of the clay mineralogy, degree of weathering and nutrient supply capability of the soil. Samples of overburden and till derived from the coal bearing formations of the Eastern Slopes indicate favorable CEC can be expected.

4.5.1.2 pH

Soil reaction (pH) serves as an indicator of conditions that influence nutrient availability, soil organism activity, physical properties of soils, and toxicity of substances.

The relationship between soil pH and plant distribution is strongly influenced by both moisture and temperature (Wilde 1958). Generally the longer the growing season the higher is the plant's tolerance of acidity and the higher the humidity the less harmful is alkalinity. For example, he states that Labrador tea supposedly has an optimum pH range of 3 to 5, and yet in more humid climates it grows well at pH 8.0.

Wilde (1958) reported that a pH of 5.0 to 7.0 has little influence on the choice of tree to be planted. This compares favorably with the pH ranges provided by Dempster and Higginbotham (1985). Wilde (1958) goes on to add that with a pH below 5.0, attention should be paid to the species to be planted and it's ability to deal with undesirable properties such as toxic levels of aluminum or iron.

4.5.1.3 Nitrogen

Vegetation and fertilizer programs that are managed to increase organic matter content of the surface layer of the minesoil have a large impact on the long-term ability of the system to be sufficient in nitrogen, which appears to be the most commonly limiting element. Increasing the organic matter content also improves cation exchange capacity (CEC) and physical properties of the soil material.

Nitrogen is needed in large amounts for plant growth and is returned to the soil as organic matter (dead roots and leaves), which is decomposed by soil microbes. Because only a small portion (<1%/yr)of the nitrogen released is not utilized by the microbes and is subsequently available to plants, a self-sustaining soil/plant ecosystem constantly requires an external input of nitrogen. The input must also account for the loss of nitrogen by leaching and volatilization.

Of the possible sources of an external supply of nitrogen listed in Table 4.5, only a few are important. In the short term, applying fertilizer and planting legumes is a viable source of supply. Long-term solutions are: (1) to grow grass to accumulate active organic matter content in the soil; and (2) to encourage native N-fixing plants to invade.

4.5.1.4 Organic Matter

Organic matter can be classified as having varying levels of activity with respect to mineralizable nitrogen, and the kinetics of the various fractions are important to an understanding of activity (McGill 1983).

An aggrading soil organic matter system (one accumulating organic matter) will be more active than a virgin soil and a greater proportion of the soil nitrogen is mineralizable (McGill 1983). The system will gradually decrease in activity to that of a virgin soil. Activity in cultivated Luvisolic soils, in which organic matter is being added from grasses or legumes, is greater than in virgin Luvisols (Campbell and Souster 1982). The total amounts of organic matter or mineralizable nitrogen depend on addition rates. The active components approach steady state in 5 to 10 years, after which activity declines with increasing accumulations of organic matter (McGill 1983).

Management of a minesoil through manipulation of vegetation and fertilizer treatments may have a considerable effect on organic matter content and the activity and amount of mineralizable nitrogen (Fyles 1984; Fyles et al. 1982; Ziemkiewicz 1979a). Grass-legume stands developed on minesoil at a Subalpine site at Sparwood, B.C. produced pools of readily-available organic nitrogen in 5 to 9 years that were capable of sustaining the stand (Fyles 1984). A large, stabilized pool of organic nitrogen was

Table 4.5 Nitrogen inputs to a developing minesoil.

NITROGEN SOURCE	IMPORTANCE	COMMENTS
precipitation	low	approx. 2 to 5 kg $ha^{-1}yr^{-1}$
N-fixation: blue/green algae	low	climate too dry/cold
N-fixation: soil bacteria	low	organic matter too low
N-fixation: exotic legumes	high	plants short-lived
N-fixation: native herbs	high	plant succession slow
N-fixation: native shrubs	medium	slow to establish
organic matter decomposition	low/high	slow to accumulate
nitrogen fertilization	high	not economic long term

also beginning to develop in nine years. This is indicative of long-term stability. Studies of a poor quality spoil on a stressed Subalpine site at Cadomin showed no development of nitrogen self-sufficiency after seven years (Takyi and Islam 1985).

The application of nitrogen fertilizers is useful on most minesoils to establish a grass or grass-legume cover quickly and to provide vigorous growth until self-maintenance is established (Fyles 1984; Fyles 1980; Lesko et al. 1975; Macyk 1978a, 1980a, 1981, 1982, 1984a; Takyi 1984b; Takyi and Islam 1985; Ziemkiewicz 1979b, 1982). On some sites, particularly in Subalpine and Alpine regions, self-maintenance may not be attained using current techniques, or at the least it may take a long time (Takyi and Islam 1985; Ziemkiewicz 1982).

The dynamics of salvaged and replaced organic matter of various forms (fibrimor, moder, mull forms) in minesoils have not been well documented. Addition of fibrimor which has a high C:N ratio, would be expected to encourage rapid microbial growth and immobilization of nitrogen in microbial biomass. Nitrogen mineralization will be low and added nitrogen may be tied up until the active organic matter fraction reaches a steady state (which may be five to ten years). The activity of replaced moder and mull forms, which have lower C:N ratios and larger active fractions, is probably highly dependent on the vegetation-fertilizer management program. If organic matter is not added to the new system, the soil organic matter levels will decrease and nitrogen can then be expected to rapidly become immobilized, after which the organic matter level will gradually increase to that of a virgin soil (McGill 1983).

A vegetation management system that quickly builds active and stable organic pools appears to be a key step in developing a self-sustaining soil-plant system, especially for grass-legume stands. Development of such a system does not require the use of salvaged soil on some minespoils, as has been demonstrated at Sparwood, B.C. (Fyles 1984, Fyles 1980; Ziemkiewicz 1979a, 1982). That self-sustaining soil-plant systems can develop naturally at other reclamation sites such as borrow pits and early mining areas has also been demonstrated (Borovsky 1979). The use of salvaged "topsoil" with good quality organic matter may, however, decrease the time required to reach self-maintenance, and cover soil (with or without organic matter) will be required on some spoils.

4.5.1.5 Phosphorus

This plant nutrient is typically one of the most tightly conserved within forested ecosystems. Harrison (1977) estimates that 35 percent of the phosphorus in the entire soil profile (including stones) is bound up in organic forms. The coversion of phosphorus into relatively unavailable organic forms is a natural process in soil development. He estimates that about 0.065 percent (1.2 kg P $ha^{-1}yr^{-1}$) of the total soil profile phosphorus may be converted into organic forms on an annual basis.

Replacement phosphorus comes from uptake by tree roots from the subsoil, weathering of rock, and release through the action of mycorrhizal fungi. The fungal activity makes it very difficult to relate soil analysis results to actual tree growth.

Generally, phosphorus can be limiting in establishing seedlings and plant invasion. However, once plants are established, phosphorus deficiency is usually not acute (Wilde 1958).

Adequate phosphorus levels are critical to legume establishment (Harapiak and Flore 1984; Johnson et al. 1977; Nielson and Peterson 1972; Vogel and Berg 1968, 1973). Phosphorus was identified as the only nutrient limiting growth of N-fixing legumes on bedrock spoil at the Fording Coal mine in southeastern B.C. (Gardiner and Stathers 1979). When phosphorus was adequate, legumes fixed up to 125 kg N $ha^{-1}yr^{-1}$.

4.5.2 Prediction of Supply

The climatic, topographic, and vegetation variables must all be considered in order to predict the nutrient regime of a site. Evaluation of the nutrient regime of a site, as done in the biogeoclimatic site classification system (Annas et al. 1983), provides a qualitative assessment of the total nutrient regime and enables ordination of sites along a nutrient gradient. Such a classification may provide a useful tool for predicting post-mine site quality and land capability.

The effectiveness of soils to supply nutrients to plants is usually related to organic matter (OM) content, pH, cation exchange capacity (CEC), and total nutrient contents (Black 1968; Monenco Consultants 1983). Soil moisture levels and the rooting medium must also be adequate to enable root systems to develop and absorb dissolved nutrients. The vegetation system and its associated mycorrhizae influence the amount of nutrients taken up and returned to the soil.

Site and climatic characteristics also influence the size of nutrient pools and flux rates. Use of organic matter content (usually expressed on a mass basis) to indicate nutrient status could be misleading, as organic matter quality is more important than quantity (McGill 1983; Rowell 1982). Organic matter contains large amounts of nitrogen, but it must be broken down to be available to plants. Carbon:nitrogen ratios in forest litter range from about 40:1 to 60:1; these ratios favor immobilization of nitrogen in microbial protoplasm rather than release of mineral nitrogen to the soil and subsequently to plants (Aber and Melillo 1980; Anderson et al. 1983; Keeney 1980; McGill and Cole 1981).

Microbial mineralization of organic nitrogen varies with total nitrogen, carbon, and other nutrients and soil reaction (Wollum and Davey 1975), and with temperature and moisture conditions (Cassman and Munns 1980). Cool temperatures and excessively wet or dry conditions limit aerobic mineralization (Weetman 1961). Considerable research has sought to relate mineralization indices of soil nitrogen availability and forest productivity, but with little success (Lea and Ballard 1982; Powers 1980). Recent work has indicated that total soil nitrogen expressed as amount per unit area by soil horizon or by profile provides the best stable measure of fertility (McColl 1984).

Few studies of functional processes in forests on minesoils were found. The following discussion of nutrient relationships is based mainly on results of various studies of natural forests and plantations, and laboratory research.

A marked redistribution of nutrients takes place over the life of the forest stand; soil nutrients decline, vegetation stocks increase to a maximum, and the forest floor continues to accumulate mass and nutrients (Gholz and Fisher 1984; Hamburg 1984; Krause et al. 1978). Rather than depleting soil nutrients, young stands take advantage of the rich surface soil resulting from site preparation and fertilization (Gholz and Fisher 1982). The rapid early growth of the stand and very slow rate of litter decomposition immobilizes plant nutrients in the forest floor and limits tree growth. The stand becomes increasingly nutrient efficient and, if efficiency limits are exceeded, the stand stops accumulating biomass.

Natural pine stands depend on periodic perturbation by fire to release organically bound nutrients in a pulse that is quickly taken up by the stand (Gholz and Fisher 1984). The forest therefore continues to grow and periodically prosper.

Management of reclaimed forests (as with managed forest plantations) should provide periodic pulses of nutrients by burning, fertilizing, or other management methods to maximize productivity. The amount of nitrogen that is available to the forest system annually through rainfall or by turnover of organic matter is insufficient for maximum productivity (Cochrane 1975; Etter 1969, 1971; Weetman and Fournier 1982). Single applications of nitrogen to some stands can provide five year volume increases of up to 30 percent, but in interior B.C. response did not correlate to soil texture, rooting depth, or moisture regime (Weetman and Fournier 1982). Studies of the relation between tree growth and site factors have found little correlation between soil nutrient levels and lodgepole pine growth (Dempster 1981; Duffy 1965; Holmes and Tackle 1982; McColl 1984).

As lateral tree roots are normally concentrated in the top 15 cm of the soil (Strong and LaRoi 1983b), it would appear that most soil nutrient cycling takes place very near the soil surface, which probably relates to mycorrhizal activity.

The forest floor or leaf litter layer contains much less nitrogen on a volume basis than the underlying A and B horizons (Ballard 1980; Krause et al. 1978); however, as much as 59 percent of the uptake of the tree is from the organic layer (Cole et al. 1967 as cited by Ballard 1980).

Turnover rates of the forest floor vary with tree species (Peterson et al. 1982). Black spruce has the slowest nutrient cycling times and subsequently has low productivity rates, while aspen and birch have litter turnover rates three times faster than those of white spruce (VanCleve and Viereck 1981. Balsam poplar, alder, and willows on floodplains are the least conservative, have the most rapid cycling of nutrients in the Boreal zone, and are very productive (Peterson et al. 1982).

Subsoil (depths greater than 30 cm) nutrients may be important in young forest stands and tend to eventually accumulate in the forest floor and surface soil layer as the forest floor develops (Comerford et al. 1984). When water deficits in surface soils limit uptake, roots in moist subsoils may maintain nutrient supplies. Comerford et al. (1984) also suggest that while subsoil nutrients appear to be important in stand development, the surface soil or forest floor becomes the primary nutrient source in mature stands.

4.5.3 Required Nutrient Level

The correlation of levels of nutrients (including N, P, K, and S) to growth response by trees or other revegetation species on mine-soils has not been done, therefore no rationale exists to identify actual minimum nutritional requirements (Ballard 1980).

Desirable and undesirable magnitudes of various soil properties can be identified, but due to additive effects, and interactions that produce more or less than the additive effects, growth response does not increase or decrease incrementally as individual limitations are overcome or imposed (Ballard 1980; Stone 1984). For these reasons, Ballard (1980, and pers. comm. 1985) stated that it is impractical to specify necessary, desirable, or optimal magnitudes of soil nutrients for reclamation. Rowell (1982) cautions that the use of agricultural soil testing methods and correlations to determine levels of "plant-available nutrients" in minesoils in the Mountain-Foothills Area may be of limited value. In the authors' opinion this could be expanded to include all non-agricultural land. There simply has not been sufficient research conducted to provide a solid correlation (and thereby allow prediction or extrapolation) between soil analytical results and plant growth in natural forest situations, to say nothing of disturbed minesoils.

The theoretical minimum requirements of soils to provide nutrients to a young grass-legume stand, to a pine stand planted into grass-legume cover, and to a mixedwood stand on oil sands tailings were estimated by Monenco Consultants (1983). This approach was based on several assumptions that have not been tested, but it provides some theoretical minimum benchmark values (Table 4.6). Desirable levels for conifer seedlings were reported by van den Driessche (1979, as cited by Ballard 1980). Use of these general values for similar revegetation types in the Mountain-Foothills Area may be valid, given the level of accuracy involved in predicting single-factor requirements of interactive systems and the heterogeneity of soil materials. Values for lodgepole pine, jack pine, white spruce, aspen, red osier dogwood, and highbush cranberry have been presented as well. The values come from a variety of areas, including Alberta, British Columbia, Minnesota, and Wisconsin, and are provided to point out the variability within a species and the similarities between chemical characteristics of many of the species.

Weetman et al. (1984) state that there is evidence to suggest that lodgepole responds to soil nutrient additions (such as fertilizer) and soil nutrient deficiencies in the same way as jack pine and Scots pine (Pinus sylvestris). They also point out that lodgepole is well known for its very wide ecological amplitude and low competitive ability. It has the ability to tolerate and grow successfully in extremely nutrient-poor sites.

Very little information is available for nutrition associated with soils on which shrubs are growing.

Table 4.6. Some levels of soil characteristics for nutrition of selected revegetation types.

Revegetation Type	pH	O.M. (wt.%)	C:N	Total N (wt.%)	CEC (me/100 g)	Exchangeable K	Exchangeable Ca (me/100 g)	Exchangeable Mg	Avail. P (ppm)	Reference
Desirable Levels										
Conifer Seedlings	4.8 to 5.5	3 to 5	<20	0.2 to 0.25	---	0.2 to 0.3	3 to 8	0.4 to 2.0	100 to 150	Vanden Driessche, 1979
Minimal Levels										
Jackpine	4.5 to 6.0	2.5		0.30	5.0	0.20	0.50	0.25	30	Monenco Consultants, 1983
Mixedwood	4.5 to 7.0	6.0		0.25	14.0	0.70	5.00	1.00	80	Monenco Consultants, 1983
Grass-legume	5.5 to 7.5	5.0		0.25	5.0	0.25	0.20	0.30	30	Monenco Consultants, 1983
Other Values										
Lodgepole pine	3.9 to 7.5	---	---	----	----	0.25	0.60	----	3 to 300	Dempster & Higginbotham, 1985
Lodgepole pine	5.5 to 7.5	0.7	---	----	----	----	----	----	--	Wilde, 1958
Jack pine	5.0 to 7.0	1.0	---	0.04	2.5	0.06	0.50	0.15	6	Wilde, 1966
Jack pine	5.1 to 5.7	2.6	---	----	----	0.11	1.16	0.52	26	Fedkenheuer, 1975
White spruce	4.7 to 6.5	3.5	---	0.12	12.0	0.17	3.00	0.70	40	Wilde, 1966
Aspen	4.6 to 5.4	2.7	---	----	----	0.15	0.79	0.40	5	Fedkenheuer, 1975
Red-osier dogwood	5.4	---	---	----	----	0.07	6.30	0.17	3	Wilde, 1946
Highbush cranberry	6.2	---	---	----	----	0.01	6.40	0.18	5	Wilde, 1946

The optimal estimated pH range for conifers and associated shrubs is 4.8 to 6.5, with a tolerable range of 4.0 to 8.0. This range covers the pH values expected of most soil-building materials in the area. The pH range for agronomic species of grasses and legumes that may be used is slightly more restricted. The estimated preferred pH range for this vegetation is 5.5 to 7.5, which is the range of greatest availability of most nutrients (Truog 1961), with a tolerable range of approximately 4.5 to 8.0. Soils with strongly acid pH can be limed to raise pH, or acid-tolerant species or varieties can be used to lessen the limitation. Strongly alkaline spoils can be ameliorated by covering with acidic coversoil, or pH can be lowered by adding sulphur.

The cation exchange capacity (CEC) required to provide a desired level of capability is difficult to identify. Monenco (1983) identified minimum CEC requirements by estimating potassium (K) demand and assuming K is 5 percent of CEC and 75 percent of the CEC is base-saturated. This CEC would also provide sufficient Ca and Mg to meet plant needs. Based on this assumption they determined minimal CEC requirements for grasses and legumes to be 5 me/100 g in the top 30 cm; for a jack pine stand of low productivity to be 5 me/100 g in the top 15 cm; and for a mixedwood stand to be 14 me/100 g in the top 15 cm and 9 me/100 g in the next 35 cm. It is important to note that this is a theoretical approach that has not yet been field-tested.

Phosphorus is an essential element that is usually deficient in newly constructed minesoils. Phosphorus adsorption capacity of minesoils and fixation of P in forms unavailable to plants must be known before phosphorus cycling and input requirements can be understood (Rowell 1982). Placement of phosphorus fertilizer at depth should provide a long-term (5 to 10 years) supply of phosphorus to revegetation plant communities as it does in many agricultural soils (Harapiuk and Flore 1984) unless adsorption capacity of the soil is high, in which case several small doses may be more effective (Rowell 1982).

Soils and spoils contain large amounts of potassium, but only small amounts are in exchangeable (slowly available) form, and less is in soil solution and readily available to plants. The exchangeable and soluble K has been shown to correlate to agricultural crop growth, but different extraction procedures may better estimate the amount of K released by rapidly weathering spoil materials in minesoils (Rowell 1982). Most analyses of spoil materials using the traditional ammonium acetate extraction show sufficient levels of K for plant growth using agricultural correlation values (McCoy 1975; Russell and Takyi 1979).

4.6 OTHER LIMITING CONDITIONS

Adverse characteristics for plant growth at a site can be due to edaphic properties or climatic-site variables. The common edaphic property perceived to be important is deficiency or toxicity of various elements.

Commercial fertilizer or soil amendents can be used to correct deficiencies at least in the short term. Burial of adverse materials during minesoil construction may reduce toxicity; however, toxic levels of elements have not been identified in the Mountain-Foothills Area.

Sodium is present in sufficient quantity to cause adverse soil properties in the Brazeau Formation, which forms part of the overburden in some mines in the Lower Cretaceous - Upper Tertiary coalfields. Sodium is generally not toxic to plants, as roots can develop in strongly sodic spoil (Barth 1984; Merrill et al. 1980), but high levels of sodium can affect soil structure and water use by the plants (Merrill et al. 1985). Recent investigations by Johnson (1985) found that the sandstone-dominated spoils from the Brazeau Formation in the Coalspur coalfield did not exhibit sodium-affected structural problems and loss of hydraulic conductivity. Bentonitic shales were the only materials that demonstrated severe loss of conductivity, but these materials only occur as thin beds that are usually mixed and diluted with non-bentonitic sandstones and shales during removal and replacement.

Salinity is not expected to be a problem in any of the spoils in the area due to the non-marine nature of the overburden. This has been shown in results of various overburden and spoil sampling programs.

Adversity due to climatic-site variables can be significant, especially in Alpine and Subalpine ecoregions. For example, southwest-facing slopes provide a very hot, dry, harsh site for plant establishment. Exposed ridgetops can also be very difficult sites to revegetate as these sites are windy and dry and plants are not only subjected to moisture stress, but also to sandblasting from mixing soil particles and extreme winter temperatures due to a lack of snow cover.

4.7 SOIL RECONSTRUCTION MATERIALS

4.7.1 Inventory Methods

Surface Soil and Regolith overburden inventories usually rely on traditional soil survey methods to map and characterize the soils and near-surface geological materials.

Bedrock Overburden inventories have received very little emphasis compared to surface soil inventories in the region. Data on inventory lithology are available from exploration drilling logs and from electroresistivity and gamma logs for many of the active mines; however, they are not summarized and were not considered in this review.

4.7.2 Quality Rating Guidelines

The value of rating the quality of surface soils and deeper overburden materials as part of reclamation planning has been recognized for many years (Schafer 1979). The purpose of this procedure is to identify quantity and quality of materials that are suitable to use for minesoil construction, or conversely are detrimental to plant growth.

The Alberta Soils Advisory Committee (ASAC) Soil Quality Guidelines for the Eastern Slopes Region (1981) assign quality class limits to various physical and chemical soil properties (Table 4.7). These class limits have not been tested and are intended as general rather than specific plant community requirements.

Knapik (1984) suggested modifications to the number of classes and class limits for specific application to growth of conifers (Table 4.8) and of grass-legume reclamation mixtures (Table 4.9). This approach of rating individual soil properties can be misleading if climate and site variables and interaction between properties are not considered. Different approaches have been taken in application of rootzone soil quality guidelines, including rating the soil quality by horizon (Brocke 1981a,b; Knapik 1983, 1984; Knapik and Westworth 1983; Knapik and Burton 1980), and rating the total soil profile to a 1 m depth as one material (Brocke 1981a,b; Parker et al. 1983).

Although the ASAC guidelines for the Eastern Slopes Region are intended to apply to surface soil to a depth of 1 m (ASAC 1981), in practice they have also been used to rate deeper overburden materials. The inference is that the quality guidelines apply to rating any of the overburden materials for use as coversoil in a similar way to the guidelines proposed for use in the Western United States as described by Schafer (1979, 1980). This suggests any suitable overburden material can be used as the surface layer of a minesoil, especially if more suitable materials are not available.

The guidelines proposed for rating overburden for use as coversoil in the Western United States (Schafer 1980) include assessment of the hardness and stability of bedrock materials, and place less emphasis on derived surface soil properties (Table 4.10). These guidelines are more applicable to rating Bedrock Overburden materials.

Table 4.7 Alberta Soils Advisory Committee (1981) proposed criteria for evaluating the suitability of soil as root zone material for revegetation in the Eastern Slopes Region of Alberta.

Rating/Property	Good (G)	Fair (F)	Poor (P)	Unsuitable (U)
Depth (cm)	>100	50 to 100	15 to 50	<15
Reaction (pH)	6.0 to 7.5	5.0 to 6.0 & 7.6 to 8.5	4.0 to 5.0 & 8.6 to 9.0	<4.0 and <9.0
Salinity (E.C.)* (mS/cm)	<2	2 to 4	4 to 8	>8
Sodicity (SAR)*	<4	4 to 8	8 to 12	>12
Saturation (%)*	30 to 60	20 to 30 60 to 80	15 to 20 80 to 100	<15 and >100
Coarse Fragments (%/vol.)	<10	10 to 25	25 to 50	>50
Texture	L,SiCL, SCL,SL,FSL	CL,SiL, VFSL	LS,S, C,HC	Consolidated Bedrock
Moist Consistence	Very friable, Friable	Loose, Firm	Very firm	Extremely firm
$CaCO_3$ Equivalent (%)	<2	2 to 20	20 to 70	>70
Modulus of Rupture (bars)**	<1.0	1.0 to 2.5	2.5 to 5.0	>5

*Measurement of these properties is generally not required in the Eastern Slopes Region.

**Modulus of rupture: Tentative limits only, pending further research.

Table 4.8 Suggested approximate criteria for evaluating the quality of soil materials for growth of conifers and associated shrubs in the Eastern Slopes Region of Alberta.

Property	Quality Rating *		
	Favorable	Tolerable	Poor
pH	4.8 to 6.5	4.0 to 4.8; 6.5 to 8.0	<4.0 >8.0
Texture	SiCL, CL, L, SCL, FSL, SL SiL, LS	C, SiC, S(>5% Si+C)	Consolidated Bedrock S(<5% Si+C)
Rock Fragments >2 mm (volume %)	<50 if AWC can be met	50 to 75 if AWC can be met	>75
Moist Consistence	v. friable friable, firm	v. firm, loose	ext. firm
Saturation %	20 to 80	15 to 20; 80 to 120	<15; >120
Salinity (E.C.) (mS/cm)	<2	2 to 8	>8
Sodicity (SAR or ESP)	<5	5 to 10 if clayey 5 to 20 if sandy	>10 if clayey >20 if sandy
$CaCO_3$ Equiv. (%)	<6	6 to 40	>40
Organic C (%)	>0.5 (best if C:N <20)**	0.2 to 0.5	<0.2
Available Water Capacity (vol.%)	>8	5 to 8	<5

*These ratings assume a site position that is freely drained on a gently sloping surface (no extreme exposure or aspect control).
Climate and site factors influence edaphic limits.

**The upper side of this range cannot currently be estimated.

Table 4.9 Suggested approximate criteria for evaluating the quality of soil materials for growth of grasses and legumes for erosion control in the Eastern Slopes Region of Alberta.

	Quality Rating *		
Property	Favorable	Tolerable	Poor
pH	5.5 to 7.5	4.5 to 5.5; 7.5 to 8.0	<4.5 >8.0
Texture	SiCL, CL, L, SCL, FSL, SL SiL, LS	C, SiC, S(>5% Si+C)	Consolidated Bedrock S(<5% Si+C)
Rock Fragments >2 mm (volume %)	<50	50 to 75 (if AWC can be met)	>75 (fragmental)
Moist Consistence	loose, v. friable, friable, firm	v. firm, loose	ext. firm
Saturation %	20 to 80	15 to 20; 80 to 120	<15; >120
Salinity (E.C.) (mS/cm)	<2	2 to 8	>8
Sodicity (SAR or ESP)	<5	5 to 10 if clayey 5 to 20 if sandy	>10 if clayey >20 if sandy
$CaCO_3$ Equiv. (wt. %)	<6	6 to 40	>40
Organic C (wt. %) (with C:N <20)	>0.5	0.1 to 0.5;	<0.1
Available Water Capacity (vol.%)	>8	5 to 8	<5

*Assuming freely drained, upper slope site positions where grasses (wild rye, fescues, wheatgrasses) preferring mesic to subxeric moisture regimes will be planted.

Table 4.10 Proposed guidelines for rating the suitability of selected overburden for use as coversoil material in western stripmine reclamation.[a]

Factor Affecting Use	Good	Fair	Poor
Texture Class	vfsl, fsl, sl, l, sil	lfs, ls, cl scl, sicl	s, c, sc, sic
Salinity (E.C., mS/cm)	4	4 to 8	>8
ESP	0 to 5	5 to 15	>15
Material or Rock Type	weakly consolidated sandstones & siltstones & unconsolidated surface deposits (i.e., loess, till, recent alluvium, and colluvium)		indurated sandstone & siltstone, shale, clayey or gravelly material
Water Slaking*	2 to 10		0 to 2
Trace Elements	less than limits at right		ppm B >8 Cd >0.1 to 1.0 Cu >40 Fe ** Pb >10 to 20 Mn >60 Hg >0.4 to 0.5 Mo >0.3 Ni >1.0 Se >2.0 Zn >40.0

[a] Source: Adapted/Taken from Schafer (1980).

* Other tests may be suitable. At least 30 percent of material should weather into <2 mm particles within one year in the surface 10 cm. A rating of 0 to 2 in the slaking test indicates that 0 to 20 percent of a fragment has passed a 5 mm sieve after 30 minutes submerged in water.

** Iron is analyzed because of antagonism with other nutrients. High Fe may mitigate high levels of other metals. Iron deficiency could also occur.

Rating guidelines should recognize the operational limitations of salvage operations as the ASAC (1981) guidelines do with a depth limit. Salvage by scrapers or by dozer and loader-truck operations limits ability to segregate layers, and the cost of handling materials in one lift is less than for handling in two or more lifts. A surface lift should have a minimum operational depth limit, in the order of 15 to 30 cm. Operational limitations imposed by slope gradient or wetness are not recognized in most guidelines, but have obvious limitations and cost implications. The usual procedure in developing a soil salvage plan is to apply the soil quality ratings to the soil map units and overlay landscape limitations and mine plans.

It is important to note that quality of materials used for minesoil construction does not necessarily correlate to growth performance of plant communities on reclaimed land. Minesoil quality is highly sensitive to topographic factors (Richardson and Wollenhaupt 1983a) and to construction and management practices (Indorante et al. 1981; Schafer 1984). Many soil properties are also subject to change (Table 4.11) as a result of mixing of surface soil horizons, long-term storage, compaction, loss of structure by puddling, enhancement of structure by plant growth, rapid weathering, oxidation of soils from anaerobic sites, and changes in acid-base buffering systems. These changes can result in effective soil properties that control rooting, moisture supply, and nutrient supply that are quite different from those in pre-mine soils. The prediction of post-mining soil quality from pre-mine soil characteristics is highly speculative without the benefit of research trials, which have not been done to date.

4.7.3 Upper Jurassic - Lower Cretaceous Materials

4.7.3.1 Quality

Bedrock Spoil has been well characterized at only one location (Tent Mountain) by McCoy (1975), who sampled reshaped spoil dumps to evaluate the quality of the surface materials for use as a rootzone. He noted that coarse fragments (>2 mm) content averaged 81.5 percent (Table 4.12) in 12 samples, and commented that fragments were generally quite soft and should weather rapidly. Nitrate levels were very low, but sufficient extractable phosphorus was present to supply a considerable portion of the P required for plant growth. Soil reaction ranged from slightly acidic to slightly alkaline, and the materials were non-saline and non-sodic. An estimate of CEC of 7.0 for the fine soil fraction indicated a possible deficiency in nutrient holding capacity. Extractable and soluble potassium levels indicated adequate supplies were present in the spoil. Water holding capacity was not evaluated, but would be low due to the high coarse fragment content (81.5%).

Table 4.11. Estimated sensitivity of soil properties to change during handling.

Soil Properties That Change Or Are Very Sensitive To Procedure	Soil Properties That Tend To Be Stable
Structure	Gravimetric water capacity
Pore-size distribution	pH (unless buffering systems change)
Air-filled porosity	
Bulk density	O.M. (except by dilution)
Volume water capacity	Salinity
Depth to restricting layer	Sodicity (can change in some situations)
Soil temperature	
Heat flux	Particle size distribution
Microbial activity	Hard coarse fragment amounts
Nutrient availability	Total nutrient amounts
Soft coarse fragment content	CEC (except by mixing)

Table 4.12. Upper Jurassic-Lower Cretaceous soil reconstruction materials.

Descriptive or Quality Parameter		
Material Type	Bedrock Spoil	Bedrock Spoil
Dominant Lithology	unknown	unknown
Location	Tent Mountain	Adanac
Data Source	McCoy, 1975	Takyi, 1984a
Coarse Fraction		
Vol. % 2 to 12 mm	42.5	n.d.
12 to 25 mm	(>12 = 39.0)	n.d.
>25 mm	n.d.	n.d.
Particle Hardness	soft	n.d.
Fine Fraction		
Fine Soil Fraction (% <2 mm)	18.5	n.d.
Texture	n.d.	n.d.
pH	7.4	4.6
EC (mS/cm)	0.7	0.2
SAR	0.3	non-sodic
CEC (me/100 g)	n.d.	13.9
NH_4OAc - extract. Ca	n.d.	n.d.
Mg	n.d.	n.d.
Na	n.d.	n.d.
K	n.d.	n.d.
Sum	7.3.	n.d.
Organic C (wt. %)	n.d.	n.d.
C/N Ratio	n.d.	n.d.
Avail. Water (0.33 to 1500 bar %)	n.d.	n.d.

n.d. = no data available, analysis of many of these parameters is difficult or has not been required in the Mountain-Foothills region.

Takyi (1984a) provided brief characterization data of "overburden" at Adanac mine. This overburden, which is assumed to be Upper Jurassic - Lower Cretaceous aged materials, had an acid pH and a fairly high CEC (Table 4.12).

There have been no data reported that characterize the Regolith or Surface Soils from Upper Jurassic - Lower Cretaceous coalfields.

4.7.3.2 Changes in Quality with Handling

Changes in quality of all overburden materials due to handling have not been documented. The Bedrock Spoil usually has low fine soil volume (less than 20 percent), but that will vary with the amount of handling. Salvaged Surface Soils and Regolith have not been characterized as to effects of mixing during handling.

4.7.4 Lower Cretaceous Materials

4.7.4.1 Quality

Levelled Bedrock Spoil from these strata have been partially characterized in the Cadomin-Luscar coalfield by Lesko et al. (1975), Russell (1980), Takyi (1984a), and Hardy Associates (1981a,b, 1983). Bedrock Spoil derived from Lower Cretaceous materials in the Smoky River coalfield was characterized by Macyk (1980a,b).

The Bedrock Overburden is predominantly non-marine Luscar Group shales, mudstones, and sandstones. The Luscar Group is overlain by marine silty shales in some areas. Bedrock Spoil is limited for use as a reclamation material primarily by high coarse fragment content, and by strongly alkaline pH related to calcium carbonate content (Table 4.13). Due to the low fine soil content, water and nutrient retention and supply capacity are low. Russell (1980) found that an available water capacity of 5 percent (weight percent corrected for rock content) was a critical limit for establishment of acceptable native plant cover on unamended Bedrock Spoil at Mountain Park.

Regolith materials occur on lower slopes and in valley bottom locations where morainal (till), fluvial, and glaciolacustrine sediments are of appreciable thickness (1 to 4 m). The Regolith materials are sandy loam to clay loam textured and have variable coarse fragment content (Table 4.14). The coarse fragment content is the parameter to be most aware of concerning use as rootzone material.

Table 4.13. Lower Cretaceous soil reconstruction materials - bedrock spoil.

Descriptive or Quality Parameter					
Material Type	Bedrock Spoil				Reclaimed spoil 2 to 10 years after seeding
Dominant Lithology	Sandstone/Mudstone				
Location	Smoky River	Cadomin-Luscar			
Data Source	Macyk 1980	Tayki 1984b	Russell 1980		Hardy Assoc. 1981a
Coarse Fraction					
Volume % 2 to 12 mm	24 (15 to 32)	n.d.			n.d.
12 to 25 mm	8 (4 to 10)	n.d.			n.d.
25 to 65 mm	19 (4 to 19)	n.d.			n.d.
>65 mm	29 (0 - 51)	n.d.			n.d.
Particle Hardness	n.d.	n.d.			n.d.
Fine Fraction					
Fine Soil Fraction (% <2 mm)	20 (5 to 60)	29	50	53	n.d.
Texture	SL to L	SL	SL	SL	SL to CL
pH	8.1 (7.9 to 8.3)	8.4	7.0	7.7	7.6 to 8.1
EC (mS/cm)	0.4 (0.2 to 0.7)	0.2	0.2	0.3	0.2 to 0.3
SAR	non-sodic	non-sodic	non-sodic		non-sodic
CEC (me/100 g)	3.8 (3.0 to 4.9)	9.3	8.8	12	9.0 to 10.4
NH_4OAc - extract. Ca (me/100 g)	22.8 (19.2 to 26.8)	n.d.	8	14	n.d.
Mg	3.04 (2.26 to 3.68)	n.d.	2	4	n.d.
Na	0.13 (0.10 to 0.16)	n.d.	0.8	0.4	n.d.
K	0.24 (0.21 to 0.28)	n.d.	0.4	0.4	n.d.
Organic C (wt. %)	n.d.	n.d.	n.d.	n.d.	1.9 to 2.2
C:N Ratio	n.d.	n.d.	n.d.	n.d.	21
$CaCO_3$ equivalent (wt. %)	11 (7 to 14)	n.d.	n.d.	n.d.	n.d.
Available Water (0.33 to 1500 bar %)	n.d.	n.d.	6	6	n.d.
Available N (lb/ac)	6 (2 to 16)	n.d.	n.d.	n.d.	20 to 68
P	4 (0 to 8)	n.d.	n.d.	n.d.	8 to 16
K	140 (110 to 160)	n.d.	n.d.	n.d.	260 to 400
S	n.d.	n.d.	n.d.	n.d.	8 to 44

n.d. = no data available, analysis of many of these parameters is difficult or has not been required in the Mountain-Foothills region.

Table 4.14. Lower Cretaceous region reconstruction materials - Regolith.

Descriptive or Quality Parameter						
Material Type	Regolith					Regolith 2 to 10 yrs. after seeding
Dominant Lithology	stony Regolith	non-stony Regolith	Till	Glaciolacustrine	Fluvial	unknown
Location	Cadomin-Luscar					
Data Source	Brocke 1981 c		Knapik 1983			Hardy Assoc. 1981a
Coarse Fraction						
Vol. % 2 to 12 mm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
12 to 25 mm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
25 to 65 mm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	n.d.	n.d.	32 (0 to 60)	2 (0 to 20)	15 (0 to 50)	n.d.
Particle Hardness	hard	hard	hard	hard	hard	hard
Fine Fraction						
Fine Soil Fraction (% <2 mm)	70 (64 to 75)	82 (76 to 88)	68 (40 to 100)	98 (80 to 100)	85 (50 to 100)	n.d.
Texture	n.d.	n.d.	SL to L	SiL to C	SL to GL	n.d.
pH	7.8 (7.6 to 7.8)	7.6 (6.2 to 8.0)	6.3 (5.9 to 6.8)	6.6 (5.5 to 8.0)	6.6 (6.1 to 7.0)	8.0 (8.0 to 8.1)
EC (mS/cm)	non-saline	non-saline	0.18 (0.09to0.28)	0.23 (0.07to0.53)	0.19 (0.10to0.33)	0.26 (0.24to0.28)
SAR	non-sodic	non-sodic	non-sodic	non-sodic	non-sodic	non-sodic
CEC (me/100 g)	n.d.	n.d.	n.d.	n.d.	n.d.	14.7 (13.9to15.5)
NH_4OAc - extract. Ca (me/100 g)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Mg	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Na	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
K	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Organic C (wt. %)	4 (2 to 6)	7 (3 to 22)	n.d.	n.d.	n.d.	n.d.
C:N Ratio	35 (21 to 48)	49 (24 to 77)	n.d.	n.d.	n.d.	1.8 (1.7 to 2.0)
Avail. Water (0.33 to 1500 bar %)	14 (11 to 21)	14 (9 to 18)	n.d.	n.d.	n.d.	19 (18 to 21)
Saturation %	n.d.	n.d.	30 (27 to 33)	46 (28 to 71)	37 (33 to 45)	n.d.

n.d. = no data available, analysis of many of these parameters is difficult or has not been required in the Mountain-Foothills region.

Peat deposits occur in many poorly drained, valley bottom locations. The peat usually occurs as thin (<1 m) blankets overlying mineral soils, but thicker local deposits also occur. The peat is fibric to mesic, with neutral to acid pH, and has value for use as a soil amendment.

Soils of the inner Foothills, Subalpine, Lower Cretaceous coalfields are developed on steeply sloping linear ridges and in narrow valleys. Soils are a mosiac of Brunisolic and Podzolic Gray Luvisols, Eluviated Dystric and Eutric Brunisols, Regosols, and Gleysols.

The soils of part of the Cardinal River Coal mine (subalpine) were rated as to quality for use as cover soil by Brocke (1981a). Most of the soils were rated as poor quality (using ASAC guidelines) due to coarse fragment content and acid pH. The A and B horizons of the soils have lower pH and almost no coarse fragments, but the BC and C horizons have high coarse fragment content and high $CaCO_3$ equivalent. Similar soil characteristics were reported at the Gregg River Resources mine by Brocke (1981a), Parker et al. (1983), and Knapik (1983). The thickness of soil development varies considerably with slope steepness, with position on the slope, and from subalpine valleys to alpine ridges. Mean overall thickness is in the order of 30 cm.

4.7.4.2 Changes in Quality with Handling

Graded and revegetated sandstone-mudstone Bedrock Spoil at Luscar was sampled 2 to 10 years after revegetating (Hardy Associates 1981a). The spoil had alkaline pH values and much higher mean CEC and organic C (Table 4.13) than values reported for Smoky River spoil by Macyk (1980b). The higher CEC suggests greater fine soil volume attributable to handling and an increase in organic C. Lesko et al. (1975) noted that low available moisture in the seedbed was the most limiting factor to revegetation of these spoils.

The eventual fine soil portion of Bedrock Spoil, which is the most important determinant of available water capacity, is highly dependent on initial amount and also type of handling. Shovel and truck mining of 15 m benches mixes the strata and produces a very rocky spoil. The rocks break up with continued handling on the dumps. The dozers rehandle the surface material several times as they repeatedly cut the slope down from the top of the dump. This results in a pulverized surface layer of approximately 15 cm thickness overlying the rocky spoil on most of the dump slope. Rock fragments also weather quickly. Lesko et al. (1975) reported a decrease from 70 percent to 40 percent in coarse fragment content in the top 2.5 cm of Smoky River spoil from early May to early August.

Regolith Overburden will be mixed when removed, stockpiled, and placed. This is not likely to affect quality of the materials, as most Regolith materials are till or colluvium, which are not sorted or layered.

Surface Soils will be mixed when salvaged, stockpiled, and replaced. This will result in loss of horizonation and mixing of LF, A, B, and upper C horizons--assuming salvage of soils is done separately from Regolith. In many places the Surface Soil plus Regolith layer is thin and the Regolith is similar in quality to the subsoil (Brocke 1981a; Knapik 1983), so the entire unconsolidated overburden is salvaged in one lift.

Brocke (1981b) compared the quality of selected Regolith materials to surface soils rated as poor due to coarse fragment content (Table 4.15) for use as coversoil at Luscar. He concluded the materials were equivalent in their suitability for use as a revegetation medium. The Regolith was more susceptible to crusting, the topsoil materials were more acidic, and they had equivalent available water holding capacity.

4.7.5 Upper Cretaceous - Lower Tertiary

4.7.5.1 Quality

Upper Cretaceous - Lower Tertiary Bedrock Overburden has been sampled in two coalfields--Coalspur and Obed. The bedrock quality varies considerably between and within these sites (Tables 4.16 and 4.17).

The above-coal bedrock in the Coalspur coalfield at Coal Valley consists predominantly of non-marine clastic sediments of variable grain size. The strata are predominantly massive or graded sandstones with interbedded siltstones and mudstones of the Coalspur Beds. The bedrock strata are generally sublithic and weather quickly when exposed and break down when handled. Very few sandstone beds are sufficiently resistant to be used as aggregate for road beds.

Bedrock stratigraphy and lithology varies considerably through the Coal Valley area due to major folding and faulting and lithofacies changes. The entire sandstone-dominated upper section tends to be strongly sodic (see Table 4.16), which is related to weathering of volcanic ash to sodium-saturated bentonite clay minerals. The lower part of the hanging wall (strata of the Coalspur Beds) has much less bentonitic content, as interpreted from gamma logs, and is predominantly sandstone.

Table 4.15. Summary of data for selected topsoil and Regolith materials at Cardinal River Coal Ltd. Luscar mine.[a]

	Topsoil Materials Less Than 25% Coarse Fragment Content			Topsoil Materials Greater Than 25% Coarse Fragment Content		
	No. of samples	Mean	Range	No. of samples	Mean	Range
Clay Content (%)	9	14.60	7 to 20	6	15.70	11 to [illegible]
Coarse Fragment Content (%)	9	8.10	5 to 18	6	31.00	22 to 40
Modulus of Rupture (bars)	9	1.16	0.5 to 2.0	6	[illegible]	0.7 to 3.0
Soil Reaction (pH)	9	5.29	4.8 to 7.7	6	5.70	4.8 to 69
Natural Moisture Content (%)	2	20.50	16 to 25	1	15.00	15
Wilting Point (%)	9	10.40	8 to 20	6	11.00	7 to 18
Available Moisture Holding Capacity (%)	9	18.60	12 to 28	6	14.00	12 to 17
Organic Carbon Content (%)	9	1.82	0.7 to 5.7	5	1.20	0.8 to 2.2
Total Nitrogen Content (%)	9	0.21	0.02 to 0.45	5	0.14	0.05 to 0.19
C:N Ratio	9	17.60	2 to 84	5	16.40	4 to 44
	Regolith Materials Less Than 25% Coarse Fragment Content			**Regolith Materials Greater Than 25% Coarse Fragment Content**		
Clay Content (%)	12	18.00	10 to 36	7	21.70	10 to 36
Coarse Fragment Content (%)	12	17.50	12 to 24	7	29.40	25 to 36
Modulus of Rupture (bars)	12	3.57	1.4 to 5.9	7	3.21	1.6 to 4.6
Soil Reaction (pH)	12	7.56	6.2 to 8.0	7	7.76	7.6 to 7.8
Natural Moisture Content (%)	12	9.80	5 to 14	7	11.00	9 to 15
Wilting Point (%)	12	10.00	7 to 16	7	12.40	[illegible] to 18
Available Moisture Holding Capacity (%)	12	14.00	9 to 18	7	13.60	11 to 21
Organic Carbon Content (%)	12	7.03	2.9 to 21.6	7	4.36	1.9 to 6.3
Total Nitrogen Content (%)	12	0.13	0.07 to 0.28	7	0.13	0.08 to 0.27
C:N Ratio	12	49.20	24 to 77	7	34.90	21 to 48

[a] Source: Brocke (1981b)

Table 4.16. Upper Cretaceous - Lower Tertiary soil reconstruction materials - bedrock overburden

Descriptive or Quality Parameter					
Material Type	Bedrock Overburden (above coal)				
Dominant Lithology	Sandstone				Mudstone
Location	Obed	Marsh	Coalspur Mynheer B	Coalspur Val d'Or	Obed
Data Source	Obed Mtn. Coal 1984		Kanpik 1984		Obed Mtn. Coal 1984
Coarse Fraction					
Volume % 2 to 12 mm	crushed samples				
12 to 25 mm	crushed samples				
25 to 65 mm	crushed samples				
Particle Hardness	n.d.	n.d.	n.d.	n.d.	n.d.
Fine Fraction					
Fine Soil Fraction (% <2 mm)	n.d.	n.d.	n.d.	n.d.	n.d.
Texture	SL	SL	SL	SL to LS	CL
pH	7.3 (5.6 to 9.1)	6.2 (4.7 to 7.8)	7.2 (4.0 to 9.8)	7.6 (5.0 to 9.7)	7.6 (4.7 to 8.3)
EC (mS/cm)	0.3 (0.2 to 0.6)	0.4	n.d.	n.d.	1.0 (0.1 to 3.7)
SAR	1.2 (0.2 to 7.0)	0.5	21 (0.8 to 80)*	2[illegible] ([illegible].7 to 99)*	4 (2 to 14.6)
CEC (me/100 g)	n.d.	n.d.	13.0 (7.5 to 17.7)	11.9 (5.9 to 16.2)	n.d.
NH_4OAc - extract. Ca (me/100 g)	n.d.	n.d.	18.1 (10.9 to 41.4)	12.8 (7.3 to 19.6)	n.d.
Mg	n.d.	n.d.	2.1 (1.2 to 3.5)	2.1 (0.8 to 4.3)	n.d.
Na	n.d.	n.d.	2.0 (0.1 to 13.2)	7.8 (0.1 to 18.6)	n.d.
K	n.d.	n.d.	0.4 (0.2 to 1.3)	0.6 (0.1 to 1.3)	n.d.
Organic C (wt. %)	n.d.	n.d.	n.d.	n.d.	n.d.
C:N Ratio	n.d.	n.d.	n.d.	n.d.	n.d.
$CaCO_3$ equivalent (wt. %)	10 (2.7 to 3.7)	0.9	n.d.	n.d.	11 (7.3 to 14)
Available Water (0.33 to 1500 bar %)	8 (3 to 15)	10 (4 to 18)	3 (2 to 4)	n.d.	n.d.
Saturation %	50 (32 to 200)	n.d.	n.d.	n.d.	56 (35 to 93)

... continued

Table 4.16. Concluded

Descriptive or Quality Parameter						
Material Type	Bedrock Overburden (above coal)			Bedrock Overburden (overthrust)		
Dominant Lithology	Siltstone	Mudstone	Siltstone	Sandstone	Mudstone	Bentonite
Location	Obed	Coalspur Mynheer B		Coalspur Mynheer A		
Data Source	Obed Mtn. Coal 1984	Knapik 1984				
Coarse Fraction						
Volume % 2 to 12 mm	crushed samples					
12 to 25 mm	crushed samples					
25 to 65 mm	crushed samples					
Particle Hardness	n.d.	n.d.	n.d.	soft	soft	very soft
Fine Fraction						
Fine Soil Fraction (% <2 mm)	n.d.	n.d.	n.d.	n.d.	n.d.	100
Texture	L					
pH	8.0 (7.6 to 8.9)	6.4 (5.8 to 7.7)	7.8 (4.5 to 9.7)	9.8	9.1	8.6
EC (mS/cm)	0.6 (0.1 to 0.8)	n.d.	n.d.	n.d.	n.d.	n.d.
SAR	3.6 (0.3 to 18.3)	0.8 (0.7 to 0.9)*	84*	49*	60*	42*
CEC (me/100 g)	n.d.	21.1 (17.4 to 25.1)	15.4 (13.0 to [illegible])	23.4	22.3	36.[illegible]
NH_4OAc - extract. Ca (me/100 g)	n.d.	21.3 (20.0 to 23.1)	10.2 (8.5 to 12.3)	16.6	19.4	39.6
Mg	n.d.	4.6 (2.5 to 6.8)	1.5 (1.0 to 2.[illegible])	1.4	1.4	3.0
Na	n.d.	0.2 (0.2 to 0.2)	14.6 (11.2 to 17.8)	11.6	13.4	16.3
K	n.d.	0.4 (0.3 to 0.5)	0.7 (0.6 to 0.8)	0.4	0.8	0.6
Organic C (wt. %)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C:N Ratio	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
$CaCO_3$ equivalent (wt. %)	8.7 (1.8 to 30)	n.d.	n.d.	n.d.	n.d.	n.d.
Available Water (0.33 to 1500 bar %)	12 (10 to 14)	9 (7 to 18)	n.d.	n.d.	n.d.	n.d.
Saturation %	49 (16 to 117)	n.d.	n.d.	n.d.	n.d.	n.d.

*indicates ESP value rather than SAR

n.d. = no data available, analysis of many of these parameters is difficult or has not been required in the Mountain-Foothills region.

Johnson (1985) attempted to: (1) characterize the interrelationships of hydraulic conductivity to degree of sodicity, content of clay and other soil properties, and (2) define the threshold concentration of soluble salts needed to maintain water flow in bedrock spoil samples from the Coalspur coalfield (spoil materials are equivalent to those discussed in this section). Sandstone spoil showed no decrease in hydraulic conductivity with lessening salt content in percolating water, apparently due to a lack of swelling or dispersion. Non-bentonitic shale spoil and mixed spoil showed less of a decrease in hydraulic conductivity than did the clayey B horizon from a Malmo soil (a non-sodic Chernozemic soil). Bentonitic shale spoil swelled and lost almost all permeability when the salt concentration of percolating water was reduced. Each kind of sodic material showed different correlations between SAR and hydraulic conductivity, which could be qualitatively predicted using saturation percentage values.

Bedrock Overburden in the Obed coalfield on the Western Alberta Plains consists of gently dipping, interbedded sandstones, siltstones, and mudstones. These are generally non-saline and non-sodic, with acid to alkaline reaction (Table 4.16) and are sublithic to lithic. Mining by dragline or shovel will produce a spoil with mixed lithology that will have variable but relatively high amounts of fines after grading. Available water capacity of the fine fraction of a sandstone-derived Bedrock Spoil will be approximately 10 percent.

Some mudstone and siltstone strata have SAR values in the 12 to 18 range and high saturation percentage, indicating that soils developed from these materials will have potentially poor soil structure and water supply.

Regolith in the outer Foothills portion of the Upper Cretaceous - Lower Tertiary coalfields consists of thin till veneers and blankets overlying bedrock ridges, and thicker till, glaciofluvial, and glaciolacustrine materials in valleys (Dumanski et al. 1972). Shallow to deep peat deposits occur in many poorly drained valley locations. These materials vary widely in quality and thickness from site to site (Table 4.17), as has been demonstrated at the Coal Valley mine (Knapik and Burton 1980; Knapik and Westworth 1983).

Regolith in Western Plains coalfields is typically till or preglacial gravels on the uplands such as at Obed Mountain and the Swan Hills Plateau. Quality and thickness varies as described at Obed by Brocke, (1981b) and at Swan Hills by Esso (1984).

Table 4.17. Upper Cretaceous - Lower Tertiary region soil reconstruction materials - Regolith.

Descriptive or Quality Parameter						
Material Type	Regolith					
Dominant Lithology	till	till	till	glaciolacustrine	glaciofluvial	peat
Location	Coalspur	Obed Mountain	Swan Hills	Coalspur		
Data Source	Knapik & Burton 1980	Brocke 1981b	Esso 1984	Knapik and Burton 1980		
Coarse Fraction						
Volume % 2 to 12 mm	n.d.	n.d.	n.d.	0	n.d.	0
12 to 25 mm	n.d.	n.d.	n.d.	0	n.d.	0
25 to 65 mm	n.d.	n.d.	n.d.	0	n.d.	0
Total	10	n.d.	24 (22 to 25)	0	20	0
Particle Hardness	hard	hard	hard	-	hard	
Fine Fraction						
Fine Soil Fraction (% <2 mm)	90	n.d.	75	100	80	100
Texture	SL to CL	SCL	CL	CL to C	SL to S	fibric-humic
pH	5 (4.8 to 5.5)	7.0 (5.1 to 7.8)	7.2 (6.4 to 8.0)	4.7 (4.6 to 5.3)	4.8	5.5 (5.2 to 7.0)
EC (mS/cm)	0.06	0.3 (0.3 to 0.5)	0.4 (0.2 to 0.9)	0.05	0.06	0.05
SAR	non-sodic	0.2	1.7 (1.0 to 3.6)	non-sodic	non-sodic	non-sodic
CEC (me/100 g)	18 (16 to 20)	n.d.	23 (13 to 28)	27 (25 to 29)	15	100 (85 to 110)
NH_4OAc - extract. Ca (me/100 g)	10 (9 to 11)	n.d.	n.d.	18 (15 to 22)	4.7	56 (45 to 69)
Mg	4 (3.8 to 4.5)	n.d.	n.d.	4.5 (4 to 5)	2	8 (7 to 9)
Na	0.1 (0.05 to 0.2)	n.d.	n.d.	0.09 (0.07 to 0.12)	0.06	0.8 (0.6 to 1.1)
K	0.3 (0.2 to 0.4)	n.d.	n.d.	0.3	0.5	0.4
Organic C (wt. %)	0.1	n.d.	n.d.	0.2 (0.2 to 0.3)	0.4	55 (50 to 58)-Org. C
C:N Ratio	10	n.d.	n.d.	12	13	25 -C:N
Available Water (0.33 to 1500 bar %)	n.d.	11 (9 to 12)	n.d.	n.d.	n.d.	n.d.
Saturation %	n.d.	43 (35 to 55)	n.d.	n.d.	n.d.	n.d.

n.d. = no data available, analysis of many of these parameters is difficult or has not been required in the Mountain-Foothills region.

Surface soils of the outer Foothills coalfields are predominantly Luvisols and Brunisols on freely drained slope positions. Many of these soils have strongly acid sola and often have acid C horizons (Knapik and Burton 1980). Gleysols and Organics occupy lower slope and depressional slope positions. Luvisol soil development thickness averages 50 cm, which varies with slope position, moisture regime, and soil material. Topography and moisture regime appear to be the major variables controlling soil productivity and soil development patterns.

Soils of the Western Plains area are typically Luvisols, with some Brunisols in freely drained positions, and Gleysols and Organics on poorly drained sites (Brocke 1981b; Dumanski et al. 1972). Soil development thickness is generally deeper than in the Foothills, with a modal depth for Luvisols of 75 cm. Soil texture, reaction, and base saturation status vary considerably from site to site.

4.7.5.2 Changes in Quality with Handling

The physical properties of sublithic bedrock change considerably when fractured, mined, moved, dumped, and levelled. The soft sandstones, siltstones, and mudstones become fines (particles less than 2 mm in diameter) with very few coarse fragments when left on the surface of a dump, ready for soil reconstuction. The coarse fragments that survive handling weather rapidly to unconsolidated fines on the dump surface. This results in sandy to coarse loamy textured spoil. Bentonite and bentonitic tuff weather rapidly to silty or clayey fines that are mixed with the other materials. The chemistry of bedrock overburden can and will change very quickly in response to mining and reclamation operations.

Knapik (1984) noted considerable decrease in pH, exchangeable sodium content, and ESP between bedrock overburden and recent and levelled bedrock spoils of materials from the same overburden formation at Coal Valley (Table 4.18). The pH decreased from 7.8 in bedrock overburden to 5.5 on the surface of a dump, and exchangeable Na from 7.8 me/100 g to 0.1 me/100 g. ESP decreased from very high to very low values.

Quality characteristics such as reaction (pH) and sodicity (SAR or ESP) measured in overburden cores can change rapidly when exposed to aerobic conditions and weathering processes. Hall and Berg (1983) noted statistically significant decreases in ESP and SAR and increases in soluble Ca with simulated weathering over several days. They also noted that ESP of overburden was overestimated from measured SAR values when the SAR-ESP relationship developed for agricultural soils (U.S. Salinity Lab staff 1954) was used. Johnson (1985) demonstrated that soil water movement could not be predicted well using only SAR.

Table 4.18. Key quality parameters of bedrock overburden and bedrock spoil from the Val d'Or mine zone, Coalspur coalfield.

	MEAN	STD. DEV.	N.	MIN.	MAX.
BEDROCK OVERBURDEN, VAL D'OR, ALL LITHOLOGY					
pH	7.8	1.88	14	4.5	9.7
CEC	17.4	8.00	14	5.9	39.3
EXCH. Ca	15.2	7.93	14	7.3	36.6
EXCH. Mg	2.1	0.99	14	0.8	4.3
EXCH. K	0.6	0.36	14	0.1	1.3
EXCH. Na	7.8	7.19	14	0.1	18.6
ESP	43.7	39.77	14	0.5	99.9
BASE %	100.0	0.00	14	100.0	100.0
CURRENT SPOIL DUMPS, VAL D'OR, MIXED LITHOLOGY					
pH	5.5	0.62	22	4.8	6.9
CEC	35.0	7.26	22	20.6	46.4
EXCH. Ca	20.6	5.17	22	13.0	32.5
EXCH. Mg	4.9	1.68	22	2.4	9.3
EXCH. K	0.6	0.14	22	0.3	1.0
EXCH. Na	0.1	0.07	22	0.1	0.4
ESP	0.4	0.25	22	0.2	1.2
BASE %	74.5	15.97	22	50.0	100.0
ORG. C%	11.5	7.28	22	3.8	26.3
LEVELLED SPOIL DUMPS, VAL D'OR, MIXED LITHOLOGY					
pH	6.2	0.89	9	5.0	7.3
CEC	30.5	10.44	9	19.1	48.2
EXCH. Ca	26.8	3.68	9	20.8	33.4
EXCH. Mg	4.5	1.26	9	2.6	6.2
EXCH. K	0.5	0.16	9	0.4	0.8
EXCH. Na	0.2	0.13	9	0.1	0.5
ESP	0.8	0.71	9	0.2	2.4
BASE %	94.6	9.15	9	77.0	100.0
ORG. C%	12.3	6.72	9	4.1	24.3
TOT. N%	0.1	0.07	9	0.0	0.2

Comparison of the Val d'or salvaged soils to individual soil horizons of surface soils (Table 4.19) indicates the salvaged soil generally is of more favorable quality. Mixing has resulted in a less acid pH and a blend of organic matter and mineral soil with favorable CEC and high exchangeable bases. This suggests the salvaged soil should provide a chemically favorable growth medium, with productivity potential at least as good as before mining, irrespective of one lift or two.

4.8 SUMMARY OF SOIL RECONSTRUCTION MATERIALS

4.8.1 Bedrock Overburden

The bedrock overburden quality is especially variable, both regionally and locally. Division of the materials into geological age groupings helps to target specific comments.

The Upper Jurassic - Lower Cretaceous (Kootenay Formation) bedrock of the southern mountains region is similar to the Lower Cretaceous Luscar Group in that it produces spoil with high rock content. The overburden typically consists of interbedded sequences of sandstone, siltstone, and mudstone that may be calcareous or dolomitic. The bedrock spoil is non-saline and non-sodic and can have generally favorable chemical properties for plant growth. Coarse fragment content appears to be the greatest limitation.

Bedrock strata of the Lower Cretaceous (Luscar Group) are strongly indurated clastics, dominated by sandstones. The materials are mostly of non-marine origin and bedrock spoil is non-saline and non-sodic, but has high coarse fragment content. Coarse fragments vary in size up to large boulders, but the surface layer of reshaped spoil slopes and dump surfaces consists of mostly fines, due to breakdown of the rock in handling. There appear to be more calcareous and dolomitic materials than in the Upper Cretaceous.

Bedrock of the Upper Cretaceous - Lower Tertiary strata that normally lie above coal deposits (the Paskapoo Formation and Coalspur beds) is typically a non-marine clastic of variable grain size, occurring in alternating strata. The sandstones, siltstones, and mudstones or claystones are generally weakly indurated and break up when handled to form bedrock spoil with few coarse fragments. The materials are non-saline and usually non-sodic, although some thin interburden layers may be sodic and bentonitic. Available water capacity of the sandstone-dominated spoils is usually in the order of 10 to 20 percent on a weight basis (Table 4.20). Strata of the Brazeau Formation occur above coal in areas of faulting and overthrust. Thin (usually in the order of a few

Table 4.19. Comparison of key soil quality parameters by soil horizon to stockpiled, salvaged soil materials.[a]

	Pre-mine Soils				Val d'Or Stockpiles		
	LFH	Ae	B	C	Topsoil (0to 30 cm)	Subsoil (30 to 60 cm)	Blend (0 to 150 cm)
pH	4.7	4.7	5.0	5.5	5.3	5.5	6.5
CEC	69	16	22	27	30	21	51*
Exch. Ca + Mg	28	4	10	23	14	14	21
Exch. Na	0.1	0.1	0.3	0.5	0.1	0.1	0.2
ESP	0.2	0.8	1.5	1.4	0.4	0.4	0.3
Base Sat. %	45	32	52	80	57	74	39
Org. C (wt.%)	30	1.6	0.8	0.9	4.3	1.8	6.8**
Total N (wt.%)	1.2	0.1	0.08	0.09	0.1	0.05	0.2

[a] Source: Knapik (1984)

* Mean is skewed by one high value (87.7), mean of other values = 31.

** Mean is skewed by one high value (16.8), mean of other values = 1.8.

millimetres) beds of volcanogenic bentonite are interlayered with the sandstones and mudstones in some lithofacies of this formation. Spoils from these strata tend to be strongly sodic and non-saline, but are dominantly sandy textured due to mixing with sandstones during excavation.

Quality and quantity of Regolith materials is highly variable from site to site (Table 4.20) both within and between mines. High coarse fragment content is the most frequent limitation to quality. Materials with fine-loamy to loamy textures are especially useful to provide water holding capacity in minesoils being constructed on coarse textured, rocky spoil. Morainal, glaciolacustrine, and some colluvial and fluvial materials are suitable for this purpose, and some may be similar in quality to the surface soil horizons.

4.8.2 Soils

The fibrimor humus layer of most forest soils is a source of organic matter of poor quality with high C:N ratio and low CEC and low AWC on a volume basis. It has value as a potential source of C and N in minesoils, but it may contribute to immobilization of N in the short term. It has value as a physical amendment to alleviate crusting and to increase air-filled porosity, infiltration, and root development, but it may limit unsaturated hydraulic conductivity and contribute to moisture stress of seedlings. The fibrimor layer may also provide a source of viable root stock and mycorrhizae inoculant.

The Ae horizon has a high silt and fine sand content, but is subject to crusting. The Bt or Bm horizons are the most suitable horizons in terms of water retention capacity due to loamy to fine-loamy textures in most situations. The BC and C horizons tend to have higher coarse fragment content, especially on upper slope positions in the Foothills and Mountains, which can limit their quality rating.

A suggested salvage plan, based on the above discussion of soil quality, is to salvage the fibrimor, Ae, and B horizons as one lift to produce a mixed material that could be superior to that obtained by individual lifts. Where BC and C horizons are of suitable quality they can also be salvaged in the one lift, and may improve the quality of the total materials by mixing lime from Ck horizons with strongly acid surface materials. Where BC and Ck horizons are of significantly lesser quality than upper horizons, mixing will lessen the quality of the salvaged material.

Table 4.20. Available water capacity of pre-mine soils and typical soil construction materials.

Soil Material	Uncorrected AWC (wt.%) (Range)	Assumed* Bulk Density (g/cm^3)	Assumed* Fine Soil Vol. (%)	AWC Vol. (%)
PRE-MINE FOREST SOILS (typical profile) (loamy)				
LFH	60(30-100)	0.1	100	6
Ae-Bm	24(16-29)	1.2	90	26
Bt	15(11-19)	1.5	90	20
BC	15(est.)	1.5	80	18
C	10(10-11)	1.8	80	14
SALVAGED AND REPLACED SOIL				
Topsoil <25% CF (Luscar)	16(12-28)	1.5	90	23
Topsoil >25% CF (Luscar)	14(12-17)	1.8	70	18
Topsoil 0-30 cm (Coalspur)	12(9-18)	1.5	90	16
Subsoil 30-60 cm (Coalspur)	11(9-14)	1.8	80	16
Topsoil (Obed)	20(17-26)	1.5	90	27
REGOLITH MATERIALS				
Till (Obed)	11(9-12)	1.8	80	16
(Luscar)	13(8-15)	1.8	80	19
Salvaged Till and Colluvium (Luscar)	14(9-18)	1.8	75	19
BEDROCK OVERBURDEN AND SPOIL				
Upper Cretaceous-Lower Tertiary (Paskapoo FM)				
Sandstone (Obed)	8(3-15)	1.8	80	12
(Coalspur)	3(2-4)	1.8	80	4.3
Shale (Obed)	15(13-17)	1.8	90	24
Siltstone (Obed)	12(10-14)	1.8	90	19
Mudstone (Obed)	10(8-11)	1.8	90	13
(Coalspur)	9(7-18)	1.8	90	14
Sandstone-dominated mixed spoil (Coalspur)	14(10-21)	1.8	80	20
Lower Cretaceous (Luscar FM)				
Sandstone-shale spoil (Mountain Park)	3(corrected)	1.8	---	5.4
Coaly shale (Mountain Park)	3(corrected)	1.8	---	5.4
Sandstone (crushed)(Luscar)	14(11-19)	1.8	60	15

* Assumed for calculation purposes only.

Soils developed under grass-forb communities usually have mull or moder humus forms, which have good quality organic matter. These horizons may be worth salvaging as distinct layers, but may be too thin to handle. Subsoil layers are of variable quality, but often have high coarse fragment content at shallow depths. In cases where thin B horizons of good quality underlie the A horizons, they can be mixed with the A horizon to increase volumes of coversoil available with no deleterious effect to the quality of the soil other than dilution of OM content on a mass basis.

4.9 RATES OF SOIL FORMATION

The rate of soil formation is a function of the intensity of the soil forming process and the susceptibility of the material to soil formation (Simonson 1959). The susceptibility is affected by: (1) permeability of the materials; (2) resistance to weathering; (3) carbonate content; and (4) physical stability (topographic position). Rates of soil formation in spoil depend on the geological material, mining and reclamation methods, time, and climate (Kohnke 1950). For post-mine soils, the influence of management must also be considered.

Rates of organic matter accumulation and dynamics have been studied by several workers who have disproven the old myth that it takes a thousand years to form an inch of topsoil. Ah horizons (mollic epipedons) have formed in 24 to 30 years in Alaska (Ugolini 1968), in 40 years in Wisconsin (Nielsen and Hole 1964), and in 50 years in North Dakota (Simonson 1959). Steady-state organic carbon was reached in 30 years in Iowa (Ruhe et al. 1975), in 60 years in Alaska (Crocker 1960), and in 7 to 10 years in minesoils in south-eastern British Columbia (Fyles 1984).

Organic matter levels can be reached fairly quickly, especially if management practices that encourage OM accumulation are used. Also, in soils with a principal limitation of low organic carbon, productivity can be attained in the short term by using fertilizers.

Since the structure necessary for air, water, and root movement is slow to develop naturally, construction and management of minesoils should aim for structural improvement. This is an area we know little about, but practices that reduce compaction and provide a permeable, aerated rootzone could be developed. Maintaining a high coarse fragment content (in the order of 50 percent of volume) may be a satisfactory method.

Weathering produces rapid changes in chemical and physical properties of spoil (Knudsen and Struthers 1953), as it does in glacial deposits (Crocker and Major 1955), and management inputs can increase these rates. Although spoil can be highly variable it is not unlike the variability found in a glacial moraine. Several studies have reported rapid rates of disintegration of shale and sandstone fragments in spoil (Down 1975; Kohnke 1950; Lesko et al. 1975).

5. MINESOIL CONSTRUCTION AND MANAGEMENT

5.1 MINESOIL DESIGN AND CONSTRUCTION

5.1.1 Minesoil Design Requirements

The properties of pre-mine soils and the requirements of soils to support herbaceous or woody plant growth were presented and discussed in Sections 3 and 4 of this report. Soil quality limits were also presented. Consideration of these has led to development of the minesoil design requirements presented in Table 5.1.

In preparing the mineral design requirements, good soil construction methods and good soil and vegetation management have been assumed. This implies:

1. Soils will not have strongly compacted layers that restrict rooting.
2. Water infiltration and movement in the rootzone will not be restricted by high bulk density (values are <1.5 g/cm^3) or low macroporosity.
3. Soils will not be constructed with layers of strongly contrasting texture within the surface 15 to 20 cm.
4. Site conditions will be compatible with the selected soil and vegetation types.
5. Seeding, planting, fertilizing, and other operations will be timely and done properly.
6. Landform shaping and surface treatments will have essentially eliminated soil losses by erosion. Areas that are eroded are repaired by top-dressing with coversoil.
7. No toxic spoil materials are expected to occur, but if they should, they will not be left on dump surfaces.

5.1.1.1 Minesoils for Grass-Legume Cover

The moisture supply requirements to support grassland cover types at acceptable levels of performance on minesoils or natural soils have not been quantified for sites in Alpine, Subalpine, and Montane ecoregions. Work by Russell (1980) suggests an available water capacity (AWC) of 5 percent (corrected weight basis) in the surface layer may be sufficient to provide adequate cover. Benchmark grassland soils have an AWC of 10 to 20 percent--equal to 1.5

Table 5.1. Summary of key minesoil requirements to provide Favorable quality.[a]

SOIL REQUIREMENTS FOR FAVORABLE ROOTING AND WATER SUPPLY IN THE:	
Rootzone Layer	Limits
1. Thickness:	
(a) grass-legume	>15 cm
(b) forest	>20 cm
2. Textural Class	all classes except clay, silty clay, and sand
3. Coarse Fragment (>2 mm) Volume	$<50\%$
4. Bulk Density	<1.5 g/cm^3
5. Porosity:	
(a) Distribution	uniform with depth
(b) Macro	$>10\%$
(c) Total	high
Subsoil Layer	
6. Family Particle Size	finer than fragmental (i.e., voids are filled)
7. Permeability	absence of restriction causing ponding for ecological moisture regimes drier than subhygric
SOIL REQUIREMENTS FOR FAVORABLE NUTRIENT SUPPLY IN THE:	
Rootzone Layer	
8. Microbiological Requirements	generally met by Rootzone requirements
9. Organic C	0.5 to 1% (wt.)
10. pH:	
(a) grass-legume	5.5 to 7.5
(b) forest	4.8 to 6.5

---

[a] Favorable quality (versus Tolerable or Poor) is expected to provide acceptable or better soil performance for growth of vegetation suited to the site and soil conditions. For a discussion of the minesoil quality, refer to the comments and assumptions found in the appropriate parts of Section 5.

to 3 cm of water storage in the surface 15 cm depth. Low bulk density and high macroporosity is important for infiltration and replenishment of soil moisture reserves. Adequate unsaturated hydraulic conductivity is necessary for water supply to plant roots. We are unable to quantify these parameters. Soils with more than 50 percent fine soil volume, with loamy particle size class, and with bulk density of approximately 0.9 to 1.3 g/cm^3 should provide suitable infiltration, storage, and hydraulic conductivity. The minimum requirement for any of these parameters depends on the interrelated factors and site conditions, but can be stated generally.

The minimal required depth and quality of rooting medium has been estimated using the following evidence:

1. Adequate grass-legume cover has been established and maintained without the use of coversoil on some spoils with reasonable management input (Esso Resources 1984; Fyles 1984; Lesko et al. 1975; Macyk 1979a,b; Takyi 1984a; Ziemkiewicz 1982).

2. With reasonable management inputs the use of coversoil often resulted in no significant increase in establishment, cover, or dry matter yield on some spoils (Esso Resources 1984; Macyk 1979a, 1980a, 1982; Takyi 1984a).

3. Varying thickness of coversoil showed no significant differences in grass cover and yield on some Lower Cretaceous spoil (Macyk 1981, 1982; Macyk and Widtman 1983).

4. After fertilization was withdrawn grass cover was no better on Lower Cretaceous spoil with coversoil than without (Takyi 1984a).

5. Nutrient content in grass-legume forage grown on topdressed Lower Cretaceous spoil was the same as on spoil (Hardy Assoc. 1983; Takyi and Islam 1984).

6. Long-term nutrient stability can be established without coversoil on Upper Jurassic - Lower Cretaceous spoil on some Subalpine and Montane sites in southeastern British Columbia in seven to ten years (Fyles 1984).

7. Lower Cretaceous minespoil is not an impermeable barrier to water movement or root growth (Macyk 1978a), but has highly variable infiltration rates related to rock and void content (Macyk 1977a).

8. Available seedbed moisture is an important factor influencing germination and establishment on Lower Cretaceous spoil (Lesko et al. 1975; Russell 1980).

9. Available water capacity of 5 percent (wt.% corrected for rock content) is correlated to satisfactory establishment and cover of native plants on Lower Cretaceous spoil (Russell 1980).

10. Establishment and growth is strongly affected by aspect (Hardy Assoc. 1983; Russell 1980), by slope position (Macyk 1982; Russell 1980), and by microsite (Hardy Assoc. 1983; Lesko et al 1975).

11. Reasonable growth and cover can be established and maintained on Lower Cretaceous spoil with a surface layer that contains acceptable (not measured) amounts of fines (Hardy Assoc. 1981a, b, 1983), but establishment appears to be faster when coversoil is used (G. Acott Cardinal River Coal Ltd. pers. comm. 1984).

Evaluation of this evidence suggests grass-legume cover can be established and maintained without the use of coversoil, at least on some sites, providing the spoil meets some quality specifications. Unfortunately, most researchers have not defined their spoil characteristics sufficiently to relate results quantitatively to soil variables.

Nutrient supply requirements of minesoils to provide performance equal to benchmark soils or to assure minimum plant cover is difficult to establish. It appears that soils that meet moisture supply requirements will also meet nutrient supply demands provided a proper fertilizer - vegetation management program is carried out. As organic matter develops in the grassland soils, nitrogen self-sufficiency can be attained on some sites in periods of as little as seven to ten years. Use of legumes in seed mixes is a proven method of adding nitrogen to the system. The major source of a continuing phosphorus supply in soils is from mineral weathering. The rates of mineral weathering and phosphorus release, and indeed the mineralogy of most spoil materials is not known. Many spoil materials are thought to have adequate levels of available potash for adapted plant species. The management option of continuing fertilizer maintenance to enhance grass productivity and cover for fairly long periods of time can also be utilized, but may not be necessary or advisable.

The requirements of Alpine Tundra minesoils to provide soil capability similar to pre-mine soils can be only roughly estimated. A minesoil profile with a minimum of 10 to 15 cm of "A" horizon overlying unconsolidated minespoil that is finer than fragmental to a depth of 30 to 50 cm should provide a favorable rooting medium and water supply. Nutrient supply and long-term cycling for adapted plant species is unknown, other than that fertilization will enhance establishment. Maintenance fertilizer may be required for an undefined time.

The "best guess" for Subalpine and Montane grassland minesoil of favorable quality are:

Horizon "A" - a seedbed depth of 10 to 15 cm with fine soil volume of at least 50 percent; 0.5 to 1 cm available water capacity; low bulk density (<1.5) and low strength; and pH in the range of 5.5 to 7.5

Horizon "B" - underlying material that is permeable but is finer than fragmental to a depth of 30 to 50 cm.

The seedbed depth will provide a rooting medium, a moisture supply, a nutrient reservoir, and should be thick enough to tolerate some loss. Nutrient pools will be developed as the soil-plant system develops.

The second horizon should be permeable to prevent saturation and ponding of precipitation or runoff, will offer rooting space to increase soil stability on slopes, and will supply some water and nutrients.

Both horizons probably can be developed from crushed Bedrock Spoil or from Surface Soils or most Regolith, or mixtures of those materials (except possibly in those rare cases where the spoil is strongly sodic). Strongly sodic materials should have a covering of at least 15 cm of better quality material on sites with a leaching moisture regime.

5.1.1.2 Minesoils for Willow Shrubland

Establishment of willow shrubland types similar to the benchmarks will require careful site selection and development of site characteristics as well as soil properties. These shrubland types require hygric moisture regimes and high levels of nutrients. These can be provided in basins or cove slopes where runon and seepage waters are ponded to suitable depths for suitable periods of time. Careful grading will be needed to ensure sites are not destroyed by prolonged ponding or deep flooding. Rooting needs are: (1) sufficient fine soil volume above the permanent watertable level with low bulk density and strength, and (2) high total porosity to provide saturated and unsaturated hydraulic conductivity. We estimate a minimum fine soil volume of 40 to 50 percent with loamy particle size class and bulk density of <1.5 g/cm^3 in the surface 15 to 30 cm, with slowly permeable materials below it, will provide suitable rooting conditions. Sediment deposition will tend to build up the surface layer over time.

Moisture supply to willow shrublands is dependent on a phreatic surface within the rooting depth. In a newly planted willow stand we estimate that the water table should be within 30 to 50 cm of the surface of soils that have properties conducive to capillary rise of water to the young shrubs. The water table depth could increase in established stands. The soil parameters listed for rooting needs should provide a satisfactory soil water regime (Table 5.1).

Nutrient supply will be continually replenished by nutrients in run-on and seepage waters, and the soil requirements listed for rooting medium should provide adequate nutrient holding capacity. The pH of the soils should be in the slightly acidic to slightly alkaline range. Organic matter will tend to accumulate in and on these cool, wet soils quite rapidly. Establishment of nutrient self-sufficiency (for both macro and micro nutrients) has not been demonstrated for these shrubland types on minesoils, but it is expected to occur rapidly due to duplication of the hydrological and geomorphic regimes.

Limiting conditions due to sodic spoil materials or seepage from such materials have not been established. Willow stands have established naturally on sodic spoils at Sterco and appear to be growing well. Willow stands also establish naturally on strongly calcareous materials, so high carbonate content is not expected to be limiting.

5.1.1.3 Minesoils for Commercial Forests

Minesoils for commercial forests encompass several soil-plant community types. The species of trees and associated vegetation must be compatible with climate and site conditions. Five forested benchmark plant communities were selected to represent a range of common forest types and ecological conditions in the Montane, Boreal Uplands, and Subalpine ecoregions. The following design guidelines represent our interpretation of what is required to provide a post-mine landscape with forest productivity equal to the pre-mine landscape. The interpretations are based on the rationale developed earlier in this report. Productivity of the forests is expected to be variable within landscapes, and to be at least as dependent on management inputs and non-edaphic factors as on construction methods and soils.

Establishment and good growth rates of tree seedlings for five to ten years have been documented on soil/spoil materials of varying quality on several mined sites in the Mountain-Foothills Area (Bertsch and Osterwoldt 1984; Dempster 1985; Esso 1984; Macyk 1984a; Macyk and Widtman 1983; Mihajlovich and Hall 1982; Russell 1979b; Selner 1973).

Research efforts designed to evaluate establishment and growth of commercial tree species have been conducted at several minesites using various soil materials and management techniques. However, none of these efforts provide data that can be used to predict the performance of bedrock spoils for growing commercial forests with an acceptable level of confidence. Most efforts have concentrated on measuring seedling height growth on "material A" or "material B", with little documentation of the many variables influencing growth and no measure of root activity or moisture or nutrient dynamics. The results from such trials have very limited predictive value.

However, it has been established that trees can grow well on minesoils in the Subalpine Ecoregion (Macyk and Widtman 1983), and on "simulated minesoils" in the Boreal Uplands (Dempster 1985; Esso 1984). Identification of the threshold limits of soil quality parameters must rely on the evidence presented in earlier sections and summarized in Table 5.1.

The surface 10 to 20 cm is the most important layer for forest soils. Most root activity in forest stands is within this depth, which corresponds with the zone of maximum biological activity, water uptake, and nutrient uptake. Deeper rooting provides anchorage and unknown amounts of water and nutrient uptake. A soil with 20 cm of rootzone with Favorable quality (Tables 4.8 and 5.1) and a subsoil layer that has no restrictions to rooting or water movement to a depth of 50 cm from the surface is expected to provide a suitable rooting environment for trees and shrubs.

Water supply requirements for forest stands must consider the ecological moisture regime suitable for the intended forest community type, and the climatic and site influences on water supply. The edaphic controls are often secondary to site factors that influence surface and near-surface water movement. Slope position and aspect and microsite preparation can have more effect on moisture regime for a tree seedling than soil depth or available water storage capacity.

Soil texture is used to indicate available water storage capacity, and, along with bulk density and porosity, to estimate water movement and aeration (Table 5.1). Loamy textures are preferable for the rootzone, but all textures other than clay, silty clay, or sand are rated favorable. Coarse (<2 mm) fragment volume should be less than 50 percent. A bulk density of less than 1.5 g/cm^3 and high porosity are also required. The subsoil layer (the 20 to 50 cm depth increment) should have family particle size finer than fragmental (the large voids between rocks are filled), and there should be no permeability restrictions to result in saturated conditions in those types that should be freely drained.

The favorable pH range for conifers and associated shrubs is 4.8 to 6.5 with tolerance (which varies with moisture content and other factors) from approximately 4.0 to 8.0. Most bedrock spoils fall within the tolerable pH range, and if they have weathered for some time the pH may be lowered to the favorable range. The pH can also be lowered by applying acid-forming substances.

Organic matter content of Bedrock Spoil is below the desired range for minesoil rootzones. Organic matter can be provided by salvage and replacement of surface soil material, but the organic matter from forest soils has high C:N ratios and is therefore of poor quality. This organic matter will act to immobilize nitrogen in the soil, making it unavailable to plants. If this material is used, a high nitrogen fertilizer should also be applied. A better option may be to grow good quality organic matter using legumes and grasses. The rootzone under a grass-legume stand will have improved structure and permeability for air and water, in addition to organic matter content.

5.1.2 Limitations of Bedrock Spoil

The Bedrock Spoil of the Mountain-Foothills region was described earlier in Section 4, and was categorized into three geological areas. Comparison of the quality parameters of the three bedrock spoil types to the minesoil design requirements of Table 5.1 provides a summary of the limitations of the spoils to support plant growth (Table 5.2). The degree of limitation is expressed in terms of: (1) not limiting; (2) often limiting, but limitations can be overcome without using coversoil (although costs may favor use of coversoil), and (3) limiting, with coversoil required to amend limitations. The "not limiting" category relates to "Favorable Soil Quality" in Tables 4.8 and 4.9 which (assuming this quality approach is valid) indicates that the soils will support rates of plant growth that are average or better for the site. The concept of relating to vegetation type and site conditions is illustrated in Table 5.2 by keying on the 10 benchmark plant community types presented for consideration earlier in this review. This is not a complete list of possible vegetation types to consider in mine planning.

Given the assumptions of good soil construction and management practices listed earlier in the section, the ratings of spoil materials for use as rootzone soils indicate the major quality limitations and degree of limitation. The severity of limitations varies with local conditions, with desired end land use and appropriate vegetation type, and with site location. The appropriate method of ameliorating limitations relates to type and degree of severity, availability of resources, management preference, and regulatory requirements. There are usually several options available (refer to Section 5.1.3) that should not be restricted by unreasonable regulations.

Table 5.2 Quality rating of Bedrock Spoil for use as benchmark plant community rootzone material.

Ecoregion/ Benchmark Type	Geological Area of Mining Activity		
	Upper Jurrassic-Lower Cretaceous	Lower Cretaceous	Upper Cretaceous-Lower Tertiary (above-coal strata)
Alpine			
1. Tundra	Site: various slopes and aspects with persistent snow cover Moisture: 1 (3 if b or c applies) Nutrients: 2 (d)	Site: various slopes and aspects with persistent snow cover Moisture: 1 (3 if b or c applies) Nutrients: 2 (d)	Not Applicable
Subalpine			
2. Grassland	Site: south to west aspects, upper slopes Moisture: 1 (3 if b or c applies) Nutrients: 2 (d)	Site: south to west aspects, upper slopes Moisture: 1 (3 if b or c applies) Nutrients: 2 (d)	Not Applicable
3. Spruce/Fir	Site: north to east aspects, moderate slopes Moisture: 1 (3 if b or c applies) Nutrients: 2 (d, e)	Site: north to east aspects, moderate slopes Moisture: 1 (3 if b or c applies) Nutrients: 2 (d, e)	Not Applicable
Montane			
4. Grassland	Site: all aspects, moderate slopes Moisture: 1 (3 if b or c applies) Nutrients: 2 (d)	Not Applicable	Not Applicable
5. Douglas Fir/ Lodgepole Pine	Site: level, to steep south aspect Moisture: 1 (3 if b or c applies) Nutrients: 2 (d)	Not Applicable	Not Applicable
6. Willow	Site: depressions, valley bottoms Moisture: 1 (3 if b or c applies) Nutrients: 2 (d)	Not Applicable	Not Applicable

Continued

Table 5.2 Concluded.

Ecoregion/ Benchmark Type	Geological Area of Mining Activity		
	Upper Jurrassic-Lower Cretaceous	Lower Cretaceous	Upper Cretaceous-Lower Tertiary (above-coal strata)
Boreal Uplands			
7. Lodgepole Pine	Site: all aspects, moderate slopes Moisture: 1 (3 if b or c applies) Nutrients: 2 (d, e)	Not Applicable	Site: all aspects, moderate slopes Moisture: 1, 2(a) if pure sandstone Nutrients: 2 (d, e)
8. Willow/Birch	Site: depressions, valley bottoms Moisture: 1 (3 if b or c applies) Nutrients: 2 (d)	Not Applicable	Site: depressions, valley bottoms Moisture: 1 Nutrients: 2 (d)
9. Lodgepole pine/ grass	Site: south to west aspects, upper slopes Moisture: 1 (3 if b or c applies) Nutrients: 2 (d, e)	Not Applicable	Site: south to west aspects, upper slopes Moisture: 1, 2(a) if pure sandstone Nutrients: 2 (d, e)
10. White Spruce	Site: north to east aspects, lower slopes Moisture: 1 (3 if b or c applies) Nutrients: 2 (d, e)	Not Applicable	Site: north to east aspects, lower slopes Moisture: 1, 2(a) if pure sandstone Nutrients: 2 (d, e)

Note: Adequate rootzone thickness (Table 5.1) is assumed.

Data Sources
- Benchmark soil data in Section 3
- Bedrock spoil data in Section 4
- Threshold limits of soil parameters in Section 4, especially Tables 4.8 and 4.9
- Key minesoil design requirements in Table 5.1

KEY TO TABLE 5.2

Degree of Limitations
1 - Not limiting
2 - Often limiting, but can be overcome without coversoil (cost may dictate)
3 - Limiting, coversoil required to amend

Type of Limitations
MOISTURE SUPPLY
a - Limiting soil texture
b - Coarse fragment content >50% in rootzone
c - Limiting subsoil particle size

NUTRIENT SUPPLY
d - Organic carbon <0.5%
e - pH outside suitable limits

Spoils from the Upper Jurassic - Lower Cretaceous area and the Lower Cretaceous area often have limitations due to high rock fragment content, low organic matter content, and high pH (in the range of 7.5 to 8). In the Upper Cretaceous - Lower Tertiary area the spoils (from strata that usually occur above the coal) do not have high rock fragment content. Key limitations that can occur are sandy textures (if sandstone is coarse and is not interbedded with mudstone), low organic matter content, and high pH. In limited locations lower strata, which often contain bentonitic and sodic layers, are overthrust and will form part of the spoil. This spoil type is expected to occur in very few locations within the Upper Cretaceous - Lower Tertiary area, and has been omitted from Table 5.2 for this reason.

5.1.3 Recommendations for Minesoil Construction

As discussed in the preceding section there are usually several options available for ameliorating spoil limitations to plant growth, therefore there are several options for post-mine landscape and soil construction. Some general guidelines are discussed below, stratified by physiographic regions, spoil type, and general vegetation type.

5.1.3.1 Topography Development

The Upper Jurassic - Lower Cretaceous and Lower Cretaceous geological areas correspond approximately to the Rocky Mountains and Inner Foothills physiographic regions. Reclamation objectives at operating mines are primarily: (a) to stabilize the soil surface against erosion and (b) to establish productive wildlife habitat; however, some lower elevation areas also have a commercial forest objective.

Post-mine topography should generally conform to adjacent topography and to requirements for the intended land uses (which in turn must recognize that a limited range in slope angles and pattern are physically and economically possible). Specific post-mine landform design is related to site characteristics, geology, and mining methods, but post-mine slopes in the Mountains and Inner foothills will usually be quite steep, except on dump tops. Surface roughness (microtopography) and frequent slope diversions or berms will help reduce soil erosion. Short slope lengths and diversity of landform pattern will enhance both erosion control and the wildlife habitat value. Areas designated for commercial forestry land use should ideally have slopes of less than 30 percent, but can tolerate gradients of up to 45 percent. In all cases vegetation establishment and erosion control will benefit from an uneven surface.

It should be noted that these are only general specifications; documented evidence of slope limitations is not available. Geotechnical engineers can provide site-specific information based on the particular materials.

The Upper Cretaceous - Lower Tertiary geological area encompasses both the Outer Foothills and the plateau uplands of the Western Alberta Plain. Coal seams may be flat-lying and near the surface, resulting in very different mining methods and dump designs than those used in the Mountains. In addition to open pit mining operations, dragline operations will probably be used, and the resulting spoils can be shaped to rolling surface forms to match surrounding landforms.

A primary reclamation objective in this area is commercial forest production. Land shaping should aim at reducing slopes below 30 percent while maintaining drainage and erosion control.

5.1.3.2 Soil Salvage and Replacement

In the Upper Jurassic - Lower Cretaceous and Lower Cretaceous geological areas the major bedrock spoil limitations (refer to Tables 4.12, 4.13 and 5.2) are anticipated to be high rock content at the surface or just below the crushed surface layer, low organic matter content, and high pH (7.5 to 8).

The effects on vegetation performance of using surface soil, Regolith, or both in varying thicknesses over bedrock spoil were assessed in the Cadomin-Luscar coalfield by Hardy Assoc. (1981a, b, 1983). Although results were inconclusive, the performance of bedrock spoil without coversoil was satisfactory, and equalled that of bedrock spoil with coversoil on some sites seeded to grass-legume mixtures. Macyk (1981, 1982) found that varying the depth of the coversoil resulted in no significant increase in establishment, cover, or dry matter yield on some spoils at Smoky River, and acceptable cover could be established on some sites without coversoil. It is apparent that coversoil is not always required, and several factors should be considered to determine need. Peat materials are sometimes recommended for use as coversoil. We caution against layering peat over spoil or partially mixing large amounts of peat into spoil due to potential problems with unsaturated hydraulic conductivity.

The need for soil salvage and replacement relates to spoil quality and vegetation requirements needed to satisfy the intended land use. The major need for coversoil is to ameliorate the condition of high rock content (Table 5.2). The required thickness will depend on the amount and size of rock fragments. A typical spoil on a dump surface might have greater than 50 percent (by volume) rock fragments, but the voids between the rock fragments are generally filled. A coversoil depth of 15 cm for grass-legume cover, or 20 cm for tree or shrub establishment should be sufficient. Spoil that is very rocky, with unfilled voids, may require 50 cm of coversoil. Spoil that has less than 50 percent rock fragments will not necessarily require coversoil.

The materials available for use as coversoil include: (1) thin (often <30 cm) surface soils on slopes, and (2) surface soils and thicker (up to 2 to 3 m) Regolith in valleys. Localized peat deposits are available for amelioration purposes. There is often little difference in quality between surface soils and Regolith (see Section 4); and the shallow depths of surface soil (or surface soil plus Regolith) provide little reason to salvage the two materials in separate lifts, assuming the decision is to salvage them.

In the Upper Cretaceous - Lower Tertiary geological areas the major bedrock spoil limitations (refer to Tables 4.16 and 5.2) are anticipated to be: low available water capacity in those areas (probably of limited extent) where coarse sandstone is not mixed with mudstone materials, low organic matter, and high pH (7.5 to 8.5). Lack of soil structure and the resultant problems with permeability to water and air within the rootzone is another quality parameter that is poorly understood and could be a limitation. Soil management techniques may be successful in ameliorating this condition.

Limited amounts of sodic spoil occur in those parts of the Outer Foothills where below-coal strata have been overthrust. These are expected to occupy a limited area, and the sandy textured spoil may not exhibit adverse structure or water movement characteristics. The sodium levels are not expected to be toxic or to inhibit root development.

The quality limitations of the bedrock spoil of this area are not expected to be severe, and in most cases can probably be ameliorated without using coversoil.

The coversoil that is available is typically of favorable quality (refer to Tables 4.8, 4.9 and 4.17), but varies in quantity both within and between sites. In the Outer Foothills physiographic region the total thickness of drift over bedrock is often less than 30 cm on slopes; and varies from less than 50 cm to 2 or 3 m in the valleys. Surface soil and Regolith often have similar quality with respect to the key parameters of available water capacity, texture, pH, cation exchange capacity, and base saturation (refer to Section 4). The lack of strong quality difference with depth and the generally shallow total depth to bedrock suggests that one-lift salvage operations, rather than two-lift, are suitable.

In the Western Alberta Plains physiographic region the thickness of soil development is greater (75 cm) than in the Outer Foothills (40 to 50 cm), and the total depth of surface soil plus Regolith is greater, being in the order of 1.5 to 3 m. If large volumes of coversoil are desired in these areas it seems reasonable to salvage it in two lifts, with the top lift being equal to the depth of soil development (i.e., the LF, Ae, and Bt of Luvisolic soils).

5.1.3.3 Improvement of Bedrock Spoil Without Coversoil

Methods of ameliorating spoil without using coversoil have been mentioned in several places in this report, and are often coincidental with good soil and vegetation management practices.

The major limitations of bedrock spoil are: high rock content, high pH, and low organic matter content. Each of these conditions can be ameliorated without using coversoil, although costs or risks may favor the use of coversoil.

Rock fragments in the bedrock spoils encountered in the Mountain-Foothills region are generally quite soft (especially in the younger geological zones) and are broken down by grading and shaping activities. They also weather quickly on the surface of dumps. Increased working of the spoil and time might reduce or even eliminate the need for coversoil on some spoils.

The high pH content of many spoils can be reduced by addition of acid-forming substances such as sulphur and nitrate fertilizers. Rainwater (a weak acid) can also lower pH quickly in some spoils. Mixing in acid peat might also help to reduce pH limitations. Many in situ bedrock overburden materials have very high pH values, but exposure to aerobic spoil environments can cause a change in buffering systems and large shifts in pH. The tolerance of plant species (especially lodgepole pine and white spruce) to pH levels in the range of 6.5 to 8 is probably very great, and these pH levels may not limit productivity. Selection of plant species tolerant of pH levels in the spoil is a management tool to ameliorate the limitation.

Amelioration of low organic matter content may be a simple matter of growing good quality grasses and legumes, rather than salvaging and replacing poor quality forest litter. The growing approach also improves soil structure, porosity, and permeability to air and water to levels that may not be attainable immediately in replaced soil. Structure and porosity are very difficult (perhaps impossible) to maintain when handling soils, and will probably have to be developed anyway. A major function of organic matter is to supply and retain nutrients, thus the agrument is made that salvage and replacement of surface soil is necessary for this supply until the minesoil has become self-sufficient. It has been demonstrated many times, however, that a good fertilizer-vegetation management program can be superior to soil replacement for short-term stand nutrition, and self-sufficiency can be attained at many sites. We suspect it can be attained at all sites with proper management.

The value of salvaged soil as a source of micro-organisms is often noted; however, there is no evidence that it is necessary for successful reclamation. Salvaged surface soil can provide viable seeds and vegetative rootstock, especially if direct-placed, but while this may be desirable at some sites it may not be at all sites, and may introduce undesirable competition for commercial forest species. Native plants will invade or can also be planted at less cost than replacing soil.

5.2 SURFACE CONTROL TECHNIQUES

The first priority after the initial steps in soil reconstruction have been completed is to ensure that the quality of the existing rooting media is not degraded by soil erosion. Revegetation is the most common method, but temporary erosion control techniques may be necessary until the vegetation becomes established. Permanent erosion structures may be required if the erosion hazard is high. The most common temporary method is the application of a mulch or the seeding of an annual cover crop; intermediate and permanent erosion control measures include surface manipulation and erosion control structures.

5.2.1 Mulches

Commonly used material for temporary erosion control includes straw, hay, wood and paper fibre, chemical tackifiers, wood chips, bark, jute netting, paper netting, sawdust, and Portland cement. Numerous reviews of these materials and their effectiveness for controlling erosion are available (Barnett et al. 1967; Kay 1978, 1983; Meyer et al. 1970; Sarles and Emanuel 1977; Swanson et al. 1965). Takyi (1980) found troughs to be relatively effective for plant establishment, growth, and erosion control compared to the roll-out mulch treatments. The paper mulch product (Hold/Gro) promotes early establishment and rapid growth (Gulf States 1976; Takyi 1980; Walker & Associates 1981), and this advantage may outweigh the disadvantages under certain circumstances.

Sims et al. (1984), in their review of international literature on mulch treatments, concluded that "soil treatments (roughening, loosening of the surface, special grading techniques) should be considered before committing to mulch" (p. 993). Further, that there are "situations where mulch could be effective on steep slopes, in harsh environments, or where soils for top-dressing are not available" (p. 992). Surface treatments should be the primary method of site amelioration, with mulches reserved for only the most difficult situations (and then judiciously selected and carefully applied).

5.2.2 Surface Manipulation

When the amount of precipitation exceeds the rate at which water infiltrates the soil, surface water accumulates and can cause serious erosion by overland flow. Techniques to intercept and channel surface flow are described in most textbooks on soil conservation (Kohnke and Bertrand 1959; Schwab et al. 1981; Stallings 1957). Designs for erosion control structures are based on well-documented engineering standards, but require data on local rainfall, slope angle, and the physical characteristics of the soil. Types of structures include vegetated waterways, ditches on slopes (water bars), furrows, terraces, earth embankments, and subsurface drainages.

5.2.3 Vegetation

The ability of various types and amounts of vegetative cover to control erosion has been quantified by the C factor in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). The C factor has been modified for construction sites and is sometimes termed the VM or vegetation management factor (Farmer and Fletcher 1976). The VM factor has been determined for various stages of growth during the establishment of a vegetative cover (Wischmeier and Smith 1978). Grant et al. (1983) refined this by calculating the rate of growth for a specific species (winter rye) in correlation with the heat units (growing degree days) received at specified geographical locations.

Effective erosion control depends on canopy cover and height of vegetation (Wischmeier and Smith 1978). Leaves that do not directly touch the soil have little effect on the amount and velocity of run-off from prolonged rains, but the kinetic energy of raindrops is dissipated when raindrops are intercepted (splash erosion). Therefore a high percentage of vegetative canopy cover controls soil detachment, reduces surface sealing, and increases the infiltration rate by extending the time available for water to be absorbed.

Plant height affects erosion rate because rain intercepted by tall-growing vegetation runs together to form large drops that contain more kinetic energy and erosive force than the rain. The erosive effect of drip height from canopy to the ground is incorporated into the USLE C factor. Figure 5.1 illustrates the combined ground (litter) and canopy (vegetation) cover for two canopy heights. Low-growing vegetation is more effective in controlling erosion at all but the highest levels of litter cover values.

Using herbaceous cover to stabilize the surface of minesoils planted to trees to protect against erosion losses can result in benefits and problems. A stabilizing surface is necessary on many sites to prevent total loss of surface soil by water and wind erosion, but in some gently sloping or depressional landscapes it is not such an obvious requirement. Questions to be asked are how much soil loss is tolerable on land reclaimed for forest land use, and how fast will a natural cover develop that will be effective in controlling erosion. The disadvantages of establishing herbaceous cover on forest sites are extra cost, competition between grasses and trees for nutrients and water, inhibition of succession to natural communities, and attraction of small mammals and ungulates that browse the trees. The advantages of the herbaceous cover, besides erosion control, include buildup of organic matter and fixation of nitrogen by legumes.

The balance between advantages and disadvantages can be expected to vary with changes in climatic, site, soil, and vegetation variables. Competition for moisture will be more intense on dry Montane sites than on northern Subalpine sites, which receive much more rainfall. Competition will also vary with aspect within a region.

5.2.4 Seedbed Preparation

The objective of seedbed preparation is to provide a suitable medium for seed germination by removing impediments to seedling emergence (e.g., surface crusts and compacted soil) and creating a favorable microenvironment for seedling establishment (e.g., through the maintenance of suitable soil temperatures and sufficient moisture reserves).

A common problem on disturbed sites in the Mountain-Foothills area is the formation of surface crusts (Macyk and Steward 1977). Soil surface crusts are usually formed after repeated cycles of wetting and drying. The impact of raindrops shatters soil aggregates, breaks down the soil structure, and sorts the particles into layers with the finer material on the surface (Stallings 1957). Once dry, the surface layer forms a relatively impervious seal that reduces infiltration and may prevent seedling emergence.

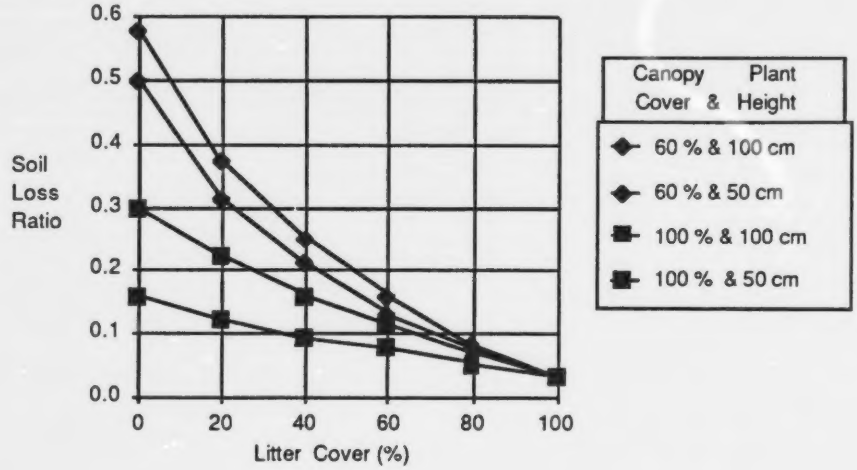

Figure 5.1. Soil loss ratio vs. litter cover (%) in relation to canopy cover and plant height. Source: Wischmeier and Smith (1978:19, Figures 6 & 7).

Modulus of rupture values are an indication of surface crust strength. Values for productive agricultural soil are approximately 100 millibars (Norwest Soil Research, February 1985, personal communication).

Moisture supply may be improved because of better contact between seed and soil and higher moisture levels through capillary movement of water. On the other hand, compacted soil may impede seedling emergence and root penetration. Large-rooted species are better able to break subsurface but tend to be less efficient in nutrient and water uptake (Haaland et al. 1977). The threshold value for root penetration depends on the type of soil and plant species. In general, clayey soils with bulk densities in excess of 1.6 to 1.8 g/cm^3 inhibit root penetration (Veihmeyer and Hendrickson 1948).

5.3 EROSION MONITORING

Monitoring erosion on mine sites is a relatively new science. Techniques for quantifying erosion losses are modifications of techniques borrowed from agriculture, and range from simple field indicators to the use of aerial photogrammetry and the application of the Universal Soil Loss Equation (USLE) under controlled experimental conditions.

5.3.1 Field Indicators

Field indicators of erosion are clues to what has happened and are generally rather crude. The absence of an erosion indicator is weak evidence of adequate erosion control unless supported by other independent evidence. Examples are soil remnants, erosion pavements, wind scours, soil deposits and gullies and rills.

5.3.2 Remote Sensing

Numerous authors have outlined methods for monitoring vegetation on disturbed lands by remote sensing (Carrel et al. 1982; Cox and Witter 1978; Krumwiede 1980), and the technology has been available in Alberta for some time (Jacques 1977; Kirby 1974).

Remote sensing can detect the presence or absence of vegetation and by inference indicate where an erosion problem may exist. Remote sensing has also been used to directly measure erosion losses of gullies (Frazier et al. 1983) and to identify potential erosion hazards due to cropping practices (Morgan and Nalepa 1982). Welch et al. (1984) described a method of measuring gullies and stream channels with stereo photographs taken vertically from a 9.5 m high platform. The images were electronically digitized and analyzed with a computer graphics program. The authors reported the procedure to be accurate and inexpensive.

5.3.3 Measurement of Erosion

Several methods are available to directly measure the erosion losses from the soil surface. Most direct measurement techniques are simple and efficient, but locating representative sites and obtaining an adequate number of samples are drawbacks. Examples of direct measurement techniques are non-movable erosion pins, portable erosion pin grids, sediment traps, and measurements of sediment by overland transport and sediment yield methods.

5.3.4 Soil Loss Estimation

A method for predicting soil erosion hazards in the Mountain-Foothills region of Alberta was developed by the Geological Survey of Canada and described by Rutter (1968). The method, suitable for non-geologists, can be used to qualitatively assess the gross erosion hazard of exposed soil through airphoto interpretation and some field reconnaissance.

Rutter lists four soil properties important in determining relative erosion hazards of soils. These are: (1) infiltration rates, (2) grain size characteristics (deposit strength), (3) carbonate cement content, and (4) the binding strength of silt and clay. External factors pertinent to predicting erosion hazards according to the Geological Survey system are: (1) presence of vegetation, (2) slope steepness, and (3) rainfall intensity. Rutter rates the overall erosion hazard from rainfall intensity in the forested region of Alberta to be low. Therefore if a good cover of vegetation exists then slope steepness is the principal factor to evaluate.

The best known model for soil loss estimation is the Universal Soil Loss Equation (USLE) pioneered by W. H. Wischmeier and others beginning in the mid-1950's. The USLE has been used in the United States to investigate potential losses and suggest management systems for mined lands (Gee et al. 1976; Mitchell et al. 1983; Stein et al. 1983). McCool et al. (1976, 1981) have refined the slope factor (LS) for steep slopes in the Pacific Northwestern United States. Monenco (1983) applied the USLE for predicting soil losses after various cultural treatments of tailings sand in the oil sands area of Alberta.

The values of several factors of the USLE need refinement before good predictions are possible in the Mountain-Foothills area of Alberta. Research on the average annual rainfall erosion factor (Rs) is needed before conditions on the East Slopes can be described accurately.

Frequent Chinook winds are a winter phenonomenon in the Mountain-Foothills Area of Alberta affecting snow cover. The problem of the snowmelt factor must be resolved before the USLE can be applied with reasonable accuracy. Other factors in the USLE that should be investigated for conditions specific to the Mountain-Foothills region are the soil erosivity value (K) for minespoils and the vegetation management factor (VM). Cool summers result in slow plant growth and existing plant cover coefficients may not be valid in the equation.

The USLE would be an attractive method of monitoring soil erosion losses in the Eastern Slopes once an adequate body of data has been acquired. Erosion control schemes can be methodically predetermined on a site-by-site basis, thus promoting the advance planning that is critical to cost-effective soil conservation.

5.4 VEGETATION ESTABLISHMENT AND MANAGEMENT

The establishment and maintenance of vegetation on a disturbed site is integral to the soil reconstruction strategy. The maintenance of a herbaceous cover with fertilizer over a period of time is a means of accumulating organic matter that can reduce the requirement for an organic matter component in a constructed minesoil. Legumes are frequently cited as a means of reducing the requirement for nitrogen fertilizer and speeding recovery to a self-sustaining state. Revegetation is frequently planned with the assumption that the initial plant cover is only temporary and that natural plant succession will inevitably occur, thus restoring the pre-existing plant community. Revegetation methods and materials therefore have an impact on the methods and materials used for soil reconstruction.

5.4.1 Grasses and Legumes

It is very important to identify the end land use objective and then select which grass and/or legume species will help the reclamationist meet that objective. A species' growth form, drought resistance, nutrient requirements and reproduction characteristics are all important in selecting species to use (USDA Forest Service 1979a). Seed availability and competition among species also must be considered.

Manipulation of seeding rate and species composition of the seed mixture can modify the site to provide adequate erosion control. At the same time, mulching the soil will minimize the accumulation of a large litter layer that could adversely affect soil temperature.

In addition to its other functions of erosion control, aesthetics, and perhaps wildlife habitat, the vegetative cover improves soil quality through the gradual accumulation of organic matter. The choice of species for the vegetative cover and the management of the cover are important to the rehabilitation of soil quality.

McGill and Hoyt (1977) suggest that uniformly distributing very fresh residue with a C:N ratio somewhat above the optimum for biomass production through the soil is the best way to achieve formation of good soil aggregates. The best agent to use for this is the roots of grasses and legumes. Therefore management practices that maximize primary production and maximize root/shoot ratio will benefit soil structure.

Grass-legume stands are established on minesoils for several reasons: (1) to stabilize the soil surface and therefore minimize erosion and protect watershed quality; (2) to build up the soil organic matter content; and (3) to provide wildlife or cattle forage.

According to Harapiak and Flore (1984), the fertilizer requirements for grass-legume mixtures have not been nearly as well established as those for a pure grass or pure legume sward. They conducted a fertilizer study on mixed forage stands in the Foothills region of southern Alberta and found that nitrogen fertilizer increased the competitiveness of grasses at the expense of legumes. The application of phosphate fertilizer enhanced the ability of legumes to compete. Ideally, this fertilizer should be added when it can be mixed into the soil prior to seeding, and starter fertilizer is not applied at the same time as the grass-legume seed, but rather three to four weeks after germination of the seed. No information was found on long-term management of grass/legume mixtures on disturbed sites in the Mountain-Foothills Area.

The approach of increasing the soil organic matter content using grass and fertilizer is in direct conflict with encouraging the invasion of native nitrogen-fixing plants. Nitrogen fertilizer applications inhibited nitrogen fixation in all legumes, and repeated heavy applications of nitrogen fertilizer usually result in grasses out-competing and replacing legumes. Native plants in general are poor competitors with agricultural plants, and this is especially true when nitrogen fertilizer is applied.

One approach to dealing with this problem is to select grass species that are low-growing and have a high proportion of their biomass in the roots rather than the shoots. This will result in organic matter being deposited primarily in the soil rather than on the soil in the form of litter. Many hay and pasture varieties of grasses are not suitable because they produce excessive thatch (litter), which lowers the soil temperature and subsequently reduces microbial activity as well as root activity. Another approach is to maintain seed mixture species at a moderately low density so that there is ample space for native plants to establish without undue competition for light, moisture, and soil nutrients. This can be accomplished by using a low seeding rate and by including some short-lived species in the mixture. Yet another approach is to fertilize the disturbed area using a moderately high rate at intermittent intervals. The amount of nitrogen should be enough to maximize plant growth and stimulate a significant amount of decomposition of plant litter. The USDA Forest Service (1979b) suggests adding 40 to 50 kg/ha of N.

The amount of available N in the soil/plant system fluctuates from a high level, at which grass species have a competitive advantage, to a low level, at which native nitrogen-fixing plants have the edge. Figure 5.2 illustrates a hypothetical situation. The years in which fertilizer is applied are theoretical estimates and will vary according to many factors, including elevation, aspect, moisture supply, and the chemical, physical, and biological properties of the soil. The fertility level is also a theoretical value. Soil nutrient requirements of both native and exotic plants in the Mountain-Foothills region are, at present, poorly understood.

5.4.2 Trees and Shrubs

Woody plants are generally established on minesoils for commercial forest production or else for wildlife habitat. They are sometimes used for erosion control as well, although not as often as grasses and legumes. Some of the shrubs are nitrogen-fixing and assist in improving site fertility.

The parameters that must be considered when dealing with the topic of woody plant establishment and management are quite similar to those involved in establishing and managing grass-legume communities.

The following references illustrate that there are many ways to establish and manage these woody plant communities, all of which will work to some degree:

1. "User Guide to Vegetation" (USDA 1979b);

2. "User Guide to Soils" (USDA 1979a);

3. "Propagation Study: Use of Shrubs For Oil Sands Mine Reclamation" (Hermesh and Cole 1983);

4. "Woody Plant Establishment and Management Program For Oil Sands Mine Reclamation" (Techman Engineering Ltd. 1983);

5. "Equipment Development & Test Program" (USDA Forest Service 1976);

6. "Revegetation Equipment Catalog" (Larson 1980);

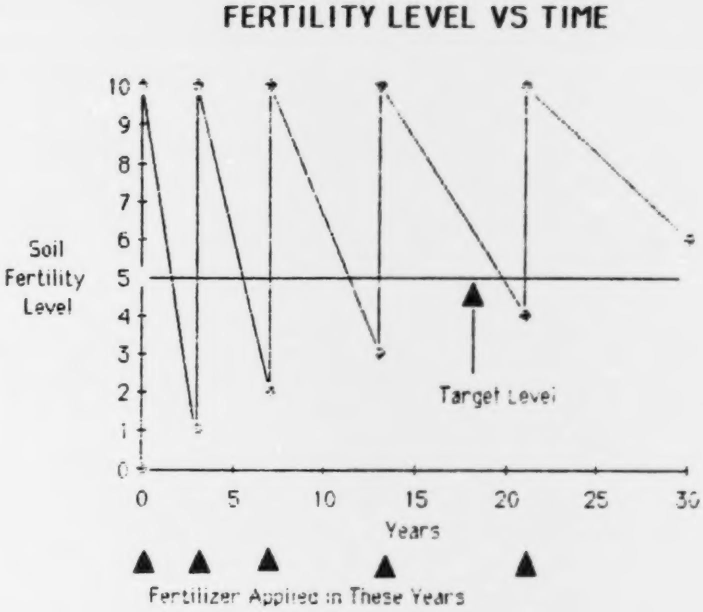

Figure5. 2 Hypothetical maintenance fertilization scheme to restore soil fertility and encourage plant succession toward the establishment of native N-fixers on disturbed lands in the foothills and mountain region.

7. "Specialized Equipment For Oil Sands Reclamation" (Techman Engineering Ltd. 1981); and

8. "A Compendium of Silvicultural Equipment" (Myles 1978).

Darby (1980) compared sites that differed in spoil quality, use of coversoil, use of vegetation cover, and fertilization practice on growth of pine in Georgia. Growth rates were reasonably similar, but the amount of erosion on the site with poor quality spoil and no coversoil was greater.

Lorio and Gatherum (1965) stated soil moisture and pH are the primary determinants of what tree species should be established on a spoil, and when these are not extreme, the next most important limitations are nitrogen and phosphorus availability. Planting N-fixing species such as alder may increase growth rates (Dale 1963; Plass 1977).

Inclusion of alder in Douglas fir stands on minesoils in Washington showed no significant effect on height growth of the Douglas fir after five years. Contour bedding treatment on the same sites did significantly increase tree growth, but resulted in higher N levels in tree foliage. It has been postulated that the benefit from an N-fixing shrub depends on competition between the tree and shrub versus the amount of N fixed and the availability and use of that N by the Douglas fir.

On sites and soils that provide acceptable rooting medium, water supply, and freedom from adversity, productivity appears to be related to nutrient availability (Lorio and Gatherum 1965). The mechanisms and rates of nutrient cycling in young forest stands (on virgin sites or minesoils) are poorly known, but the accumulation of nutrients in the forest floor at the expense of soil reserves and very slow cycling in coniferous stands has been documented (Comerford et al. 1984; Gessel et al. 1973; Gholz and Fisher 1984; Hamburg 1984; Jorgenson et al. 1980; Switzer and Nelson 1972). The nutrient transfer from the soil to the organic pool is evidence of nutrient uptake and utilization by the young forest stand. The exact amounts of N and other nutrients required, and the effectiveness of organic sources versus fertilizer sources is expected to be highly dependent on site, soil, and vegetation variables. Productivity of the forests is expected to be variable within landscapes, and to be at least as dependent on management inputs and non-edaphic factors as on construction methods and soils.

Establishment and good growth rates of tree seedlings for 5 to 10 years have been documented on soil/spoil materials of varying quality on several mined sites in the Mountain-Foothills Area (Bertsch and Osterwoldt 1984; Esso Resources 1984; Macyk and Widtman 1983; Macyk 1984a; Mihajlovich and Hall 1982; Obed Mountain Coal Co. 1984; Russell 1979b; Selner 1973). In most cases establishment did include fertilization with an NPK fertilizer.

Tree seedlings and young trees, especially lodgepole pine, respond to fertilization, and established stands may rely more on pulses of nutrients due to fire adaptation than on turnover of organic matter and mineralization of nitrogen (Gholz and Fisher 1984). A long-term fertilization program of forested minesoils is advisable to maximize productivity (assuming the operator is attempting to maximize growth) by supplying periodic pulses of nutrients. Periodic burning of the sites may be equally effective in releasing organically-bound nutrients.

Replacement of salvaged surface horizons of forest soils is expected to provide nutrient cycling capability in a minesoil, but this capability can be developed in spoils without coversoil in 5 to 10 years, as has been demonstrated at Sparwood, B.C. under a grass-forage cover (Fyles 1984). The extent to which this can be developed appears to depend primarily on the severity of the site, the quality of the spoil, and the vegetation-fertilizer management program.

Phosphorus can be added prior to seeding and mixed into the soil. Appropriate mycorrhizal fungi reduce P deficiencies (Marx 1980) and provide a protective shield for roots exposed to low pH soils and high levels of soluble aluminum (Cochrane and McNabb 1979). Micro-organisms generally increase plant nutrient availability and uptake, increase soil moisture availability, and increase a plant's survival and tolerance of extremes of pH, soil temperatures, and toxins, and an attempt should be made to enhance their numbers. The methodology associated with increasing microbe numbers is not clear for minesoils; however, they do need carbon and this is one nutrient often in short supply on disturbed minesoils. Visser et al. (1984a) suggest initially planting a short-lived grass species such as slender wheatgrass, which can produce large quantities of dead roots, tops, and exudates (i.e. large amounts of carbon), and then following this with the longer-lived woody species. This could serve to both build up the organic matter content and stimulate micro-organism activity.

Whether mycorrhizal fungi need to be introduced with seedlings also is in some doubt Dr. R. Danielson is currently conducting a survey of container-grown material in Alberta to ascertain whether it is mycorrhizal and whether an inoculation program might be worthwhile (R. Danielson, U. of C., pers. comm., 1985).

Introduced grass species also compete with tree seedlings and other native woody species. Gautier (1983) reported that annual ryegrass seeded on burned areas to temporarily reduce erosion had a significant effect on the subsequent recovery of the native shrub community. Clark and McLean (1975) reported that growth of lodgepole pine seedlings was progressively diminished as density of orchard grass increased under greenhouse conditions. The response was independent of soil moisture. Wilde et al. (1968) reported a 50 percent loss in expected volume of merchantable timber due to weed competition. Dempster (1985) reported finding a serious adverse effect on seedling survival and height growth from seeding agronomics at the time of planting.

Macyk (1984a) stated that a grass-legume nurse crop was a necessary pretreatment for successful tree growth on Subalpine minesoils in the Smoky River Coalfield, but not on southern aspects. He feels that this provides sufficient nitrogen to the seedling without having to apply commercial fertilizer. Perhaps the key in his studies is that, as well as providing N, the alfalfa plant reduces the grass competition for moisture in the seedling root zone as the alfalfa root is obtaining its moisture from deeper in the soil material. The alfalfa plant may also provide some shelter for the seedling from the wind in both winter and summer, as its stalks are somewhat slow to decompose. It appears that at the high elevations of Macyk's study area, a grass-legume or perhaps a legume-only companion crop is desirable, even though the reasons may not all be clear.

At other sites, such as some in Coal Valley, there may be no need for a grass-legume companion crop. A rough surface, not flat, provides suitable microsites for many of the native species to invade and grow along with planted seedlings. Certainly erosion-prone sites will need to be grassed.

6.0 RECLAMATION EVALUATION

6.1 EVALUATION OF RECLAMATION SUCCESS

Evaluation of land reclamation success should logically relate to satisfaction of the stated objectives of providing land use potentials, soil stabilization and watershed protection, productivity, optimum use of soil materials, and aesthetic values. The maxim to do the best possible reclamation for the smallest practical cost (private and social) governs all of these objectives.

There are several possible approaches and techniques for evaluation of success. Ries and Hoffman (1980) noted that all approaches require four common or initial decisions:

1. The desired post-mine land use;
2. The characteristics of reclaimed land that should be measured to show success;
3. The standard to which the reclaimed land will be compared; and
4. The method of comparing the reclaimed land to the standard.

Ries and Hoffman (1980) commented that these initial decisions can be made using scientifically developed information and qualitative professional judgement, but the final determination of success must be quantitative to best serve all interests. This assessment appears to be directly applicable to the subject area.

Since comparisons to success standards could have expensive ramifications if unfavorable, and will undoubtedly be challenged, the methods used must be objective, reliable, and defensible. Qualitative methods relying on subjective judgement do not satisfy any of these requirements.

6.2 RECLAMATION APPROACHES

6.2.1 Productivity Approach

The productivity approach is usually based on measurement of selected vegetation performance indices (biomass yield, cover, diversity, forage quality, tree height growth) that are considered to be measures of soil performance. While the preferred plant species can be thought of as the ultimate integrator of site and soil factors, several problems have been identified with this approach in the U.S. (Kleinmann 1984, Munshower and Fisher 1984; Murdock 1980). Wali (1980) noted that landscape stability rather than vegetation stability should be stressed in approvals. Green (1980) and Cairns (1983) felt that all components of an ecosystem should be evaluated rather than just a few. Green recommended that soil moisture regime, mycorrhizal establishment, organic matter decomposition, N-fixing rates, diversity of plants and animals, and evidence of regeneration and reproduction be evaluated. Also, reclamation is a dynamic process, and the use of static measures like productivity, cover, or diversity may be inappropriate to identify trends. Measurement of vegetation gives little indication of how the minesoil is maturing to provide long-term success of the ecosystem (Munshower 1982). Management inputs have a neat effect on productivity, which has led to unrealistic restrictions being placed on operators to allow measurement of productivity and comparisons to reference areas (Kleinman 1984; Murdock 1980).

The principle of requiring minesoil landscapes to perform similarly to climax or late seral ecosystems has no basis in science and may be unrealistic (Cairns 1983; Kleinmann 1984; Murdock 1980). Productivity is easy to measure, but may not reflect how well an ecosystem is progressing toward nutrient self-sufficiency. High productivity of above-ground biomass of grasses may indicate poor nutrient use efficiency (Ziemkiewicz 1979b).

The major influence of non-soil factors such as microclimate; topography; plant genetic traits; and planting, fertilization, and other management inputs on productivity makes it very difficult to isolate the soil effect in many trials. Productivity is a measure of performance of the total ecosystem (including management), but can be a poor measure of soil quality. The many problems encountered in identifying the soil effect on productivity of natural forest stands (Corns 1978; Stone 1984) underlines the limitations of this approach.

Given the small amount of empirical data available and the lack of a rationale to generalize to widely varying site conditions and management practices, the productivity approach is currently of limited applicability for determining minesoil requirements or evaluating short-term success, but it has potential for evaluating long-term success.

6.2.2 The Capability Approach

The capability approach identifies the climatic and physical (topographic and edaphic) characteristics that limit productivity potential and the range of management options for the soil landscape (Smith et al. 1974). It is therefore less dependent on the influence of vegetation and management variables that greatly affect productivity (although a vegetation management system is assumed). Capability evaluation usually provides qualitative assessments of the nature and degree of limitation (Macyk 1984b; Schafer 1979), but by their very design the classes are not intended to be quantified. Lack of quantification and the subjective nature of assessment limits the value of this approach in reclamation evaluation.

This approach relies more on a general understanding of site performance rather than specific correlations of single factors to growth, which makes it applicable to evaluating large areas with limited empirical data; however, the amount of error is inherently large. The limitations imposed by adverse soil landscape properties such as excessive wetness, shallow depth to restricting layers, and climatic limitations are used to rate inherent site capability. The function of individual soil properties and their response to management is assumed, which may or may not be valid.

The effects of management, including choice of vegetation materials and fertilizer programs, are often more important than soil factors in determining productivity. In this regard, minesoil management is more like farming than wildland forestry in that if the effects of management practice do not positively affect productivity, management is altered until it does. The inherent productivity of the site is not as important as the response to management, except in extreme situations. This is a further limitation of the capability approach.

6.2.3 The Functional Analysis Approach

The functional analysis approach (Johnson 1980; Monenco Consultants 1983) identifies the factors that interact to control the performance of an ecosystem. This approach has been used to identify minesoil requirements (Monenco Consultants 1983 and this report).

The factors that control landscape performance relating to the rehabilitation objectives of providing land use potentials, soil stabilization and watershed protection, productivity, and aesthetic values, should be measured to determine how well they provide the desired functions. This requires identification of the key factors and knowledge of functions and interactions, and may require development of new measurement and modelling techniques. This approach has the value of being utilitarian--rather than measuring the similarity of the land to the pre-mine condition, the requirements of the intended land use are measured. Measurements can be quantitative and can be compared to design requirements. Topographic and soil parameters can be measured directly and correlated to plant function or productivity measures to further identify the functional properties of minesoil ecosystems. This approach also fits well into monitoring and management programs (Johnson et al. 1984; Munshower and Fisher 1984).

To satisfy the rehabilitation objective of optimum use of soil materials, the requirements of the soil handling plan developed for the site must be met. The characteristics to be measured are the soil material depths and volumes specified for salvage and replacement or special handling.

Evaluation of landscape form, line, color, texture, and other aesthetic qualities is not normally practised in Alberta, and standard procedures have not been developed. Procedures are available from the United States (Litton 1968; USDA Forest Service 1974a, b), and similar procedures have been applied in British Columbia (Hirvonen 1976). The visual appearance of the landscape will be the parameter used most often by the general public to judge reclamation success.

6.3 CHARACTERISTICS TO MEASURE

The intended post-mine use of a site must be clearly identified at the outset in order to determine just what topographic, edaphic, and vegetational characteristics will be required at the reclaimed site (Cairns 1983; Green 1980; Kleinmann 1984, Mains 1977; Marshall and Godfrey 1977; Murdock 1980).

The pre-mining land uses of major interest in the Mountain-Foothills Area are commercial forest, wildlife habitat, erosion control for watershed protection and rangeland, and recreation. Primary land uses of post-mine lands involve combinations of the same land use potentials that existed prior to mining.

An objective of reclamation is to make mining a temporary land use, and to return the site to a level of site use potential equal to or better than before mining. However, within a post-mine landscape there are varying opportunities for, and limitations to, development of certain types of land units. Pre-mine topography, coal geology, and mining methods combine to produce the gross post-mine landscape characteristics, which are modified to some degree by spoil shaping and grading as part of the reclamation process. The costs of handling materials and opportunities for development of alternate landscapes leads to the need for a land use plan as part of mine planning. The development of post-mine land use plans and landscape design is a site-specific planning exercise that should be done in conjunction with the development of the mine plan.

Characteristics to be measured to determine success should be those that indicate how well the reclamation objectives and the approved plan have been met. The characteristics will vary with land use goals, site requirements for stabilization, productivity requirements of desired ecosystems (e.g., trees, forage or browse) soil salvage or other handling requirements, and aesthetic requirements. Measurement of several variables is required on a site-specific basis.

It is apparent that some minesoil landscape characteristics are developed immediately (landforms, soil depths); some develop over one to three years (grass cover, tree seedlings); and some take 5 to 20 years or longer to develop (nutrient cycling, native plant invasion, wildlife cover, forest stands). Measurement of success can be done at various stages, with different variables measured at different times.

In the U.S. evaluation of spoil shaping and topsoil replacement can be done when those operations are complete and part of the reclamation bond can be released (Munshower 1982). Evaluation of long-term success is tied to productivity and comparisons to reference areas as provided for in Public Law 95-87, The Surface Mining Control and Reclamation Act, 1977 (as cited by Kleinmann 1984).

The characteristics most often considered for measurement are ones that identify the land productivity, the land capability (limitations to productivity), or the functioning of various parts of the ecosystem.

Reclaimed soils may be better able to satisfy the requirements of the post-mine vegetation by having characteristics that differ from those of pre-mine soils. For example, development of a root zone with biologically active organic matter derived from turnover of grass and legume roots may provide a better establishment and growth medium for trees and shrubs than natural forest soils.

Success standards based on performance of pre-mine lands must recognize differences between ecoregions and sites. Benchmark ecosystems that identify pre-mine land values (including productivity, capability, and other measures of land value) provide standards that relate to the ecological conditions of a site. Similar site positions with comparable moisture regimes (Ecological Response Units of Cook and Bonham 1977) can be expected to perform similarly in pre- and post-mine landscapes. Functional processes and relationships of soil and site variables to performance can also be expected to compare better between ecologically similar sites than between dissimilar sites.

6.4 COMPARISON TO STANDARDS

The method of comparing reclaimed land to success standards must involve quantitative procedures that can be replicated with precision to best serve all interests (Murdock 1980; Ries and Hoffman 1984). Qualitative methods based on judgement of an interpreter are subject to opinion and are difficult to replicate or substantiate.

Comparison to standards essentially follows one of two approaches: (1) comparison to absolute values or specifications (Doll et al. 1984) and (2) comparison to adjacent reference areas or to pre-mine landscapes.

Comparison to absolute values requires: (1) the development and application of design criteria; (2) quality control during construction to ensure specifications are being met or are developed during a targeted post-construction time period; and (3) final inspection to identify attainment of standards. This approach is similar in concept to that used for construction of highways or other structures. There are two main concerns addressed in this approach: (1) how well current technology is being applied and (2) whether the technology will be successful. The approach requires a technology to be adopted and used for design, construction, and measurement of success. If the technology is not successful, it is modified for the next application.

Comparison to reference areas to identify success is a standard procedure in the U.S., with measurements being based on statistical comparisons of vegetation growth characteristics. This procedure has several shortcomings (Cairns 1983; Doll et al. 1984; Kleinmann 1984; Munshower 1982; Murdock 1980; Redente et al. 1983; Ries and Hoffman 1984). The most limiting aspects of this procedure appear to relate to lack of recognition of land use flexibility, lack of recognition of different functional processes in reclaimed landscapes, problems with statistical comparisons, and lack of similarity between reference areas and the pre-mine landscape. Sampling procedures can also be costly and are subject to error (Cairns 1983; Green 1980; Kleinman 1984; Munshower 1982; Murdock 1980).

6.5 RECOMMENDED FACTORS, STANDARDS AND TIMING

6.5.1 Factors To Measure

The companion studies to this report, dealing with reclamation for commercial forestry (Dempster and Higginbotham 1985) and for wildlife habitat (Green et al. 1985), both suggest a functional analysis approach to measurement of success. Evaluations of landscape and soil reclamation must be coordinated with an evaluation of forestry and habitat requirements as was pointed out by the above authors.

The functional analysis approach identifies the factors that interact to control ecosystem performance, and these factors and relationships are what must be measured to: (1) understand ecosystem function and to develop predictive models, and (2) provide a true indication of reclamation success. The factors involved include climatic, topographic, soil, vegetation, wildlife and management parameters interacting over time. Many of the climatic, topographic and soil variables that affect rooting and water and nutrient supply have been discussed in depth earlier in this report. Our understanding of the function of pre-mine and post-mine landscapes is incomplete and requires considerable effort to identify and understand (essentially to model) the systems to identify optimal or minimal levels of various controlling factors. Those factors that account for most of the variability in net primary productivity of forest and grassland ecosystems are probably ones that control moisture supply, but this must be confirmed.

6.5.2 Success Standards

We suggest that success standards should focus on construction specifications derived from measurement of pre-mine conditions. The success standards should be specific to the mine area, and should recognize differences in forest productivity potential between sites in the area (as suggested by Dempster and Higginbotham, 1985), and distribution and number of Habitat Units (as suggested by Green et al. 1985). The end land uses must be specified and must be compatible with success standards.

The method of comparing reclaimed land to success standards must involve objective, quantitative procedures that can be replicated with precision. The approach should compare post-mine characteristics to the standards specified in the approved reclamation plan rather than to reference areas.

6.5.3 Timing

Evaluation of success in the Mountain-Foothills Area should be time-staged in perhaps two steps: (1) evaluation of spoil shaping and soil construction and (2) evaluation of long-term stability. This would require measurement of different characteristics, use of different standards at each step, and use of more than one comparison method. This may appear cumbersome, but is necessary to evaluate landforms, soils, water, animals, and plants.

Evaluation of landforms and soils immediately or shortly after construction has some obvious advantages:

1. Problem areas can be identified and remedial action taken immediately rather than after several years.

2. Vegetation management and surface treatment requirements can be identified or modified as a result of the evaluation.

3. The reclamation performance bond can be returned to the operator in stages.

4. Measurement of topographic and soil properties can provide an evaluation of capability or land use potential independent of plant growth measurements.

Such an approach has been proposed for use in the U.S. (Redente et al. 1983) and in Alberta (D & R Review Comm. 1984). The approach has the advantage of relating directly to the utility of the mine-soil landscape (land use goals) rather than relying on an indirect measure of soil quality such as plant growth rates. Poor growth rates related to species suitability or planting techniques are thus not construed as soil quality deficiencies.

The development of long-term stability is a dynamic process and may be best determined using sequential analysis methods to substantiate rate and direction of development. One approach to identification of long-term success is to measure various indicators of functional capacity, including vegetation performance and soil characteristics indicative of maturation (Munshower 1982). Establishment of nutrient cycling capability of a soil-plant system has been identified as one of the most important aspects of stability (Fyles 1980; Monenco Consultants 1983; Parton and Woodmansee 1980; Ziemkiewicz 1979b).

Prediction of long-term success and evidence of ecological stability require information derived from long-term monitoring and evaluation of plant growth and functional capacity of the entire landscape. This information base is not currently available.

7.0 RESEARCH

This section discusses what information is lacking from the data base needed to make economically and ecologically sound decisions regarding minesoil and landscape reclamation in the Mountain-Foothills region. This is followed by a discussion of which existing research will fill those data gaps or if any plots can be modified to provide information to fill the gaps. The chapter concludes with a presentation of research necessary to fill the remaining data gaps.

7.1 INFORMATION GAPS

It should be understood that not all of the information gaps identified below require research. Some of the problems can be resolved by making some procedural changes.

7.1.1 Reclamation Planning

A key part of this area is timely reclamation planning. To a great extent economic and effective reclamation depends on determining the end land use objective as a first step. Plans should be made before materials are handled. This provides the best opportunity for dealing with adverse physical or biological conditions and will permit maximum flexibility in mining and use of the resource. This also eliminates the short-term outlook and forces everyone to look at the longer term. Instead of only being concerned with first making sure that an area will not erode by overseeding with a grass-legume seed mix and then worrying about how to get trees or shrubs to grow in the thick cover, a plan should be thought out and followed logically.

7.1.2 Spoil Placement and Grading

Information in this area is lacking with respect to:

1. The effectiveness of erosion control techniques (vegetation or other) in controlling surface erosion.
2. How much erosion is acceptable.
3. Cost effectiveness of various erosion control measures.
4. How to best integrate materials handling and topographic constraints into the planned used of the reclamation area.
5. Spoil characterization and classification criteria.
6. Appropriate land forming operations to trap, collect, and conserve water for hygric communities and water-bodies.

7.1.3 Soil Preparation and Treatment

Information in this category is lacking in the following areas:

1. Rootzone requirements for various plant species and plant communities based on the intended land use.
2. The value of topsoil versus spoil as a plant growth media.
3. The effect of time on topsoil and spoil both in a stockpile and in place with plants growing on them.
4. The value of topsoil as a seed or plant stock source.
5. The effects of various soil amendments such as peat, LFH material and fertilizers on soil erosion, compaction, water infiltration and retention, and soil structure and nutrient availability.
6. Textural differences Thatt inhibit roots moving from one strata to another.
7. Mineralogy of the spoils.
8. Trace elements released by weathering.
9. Rates of spoil weathering.
10. Types and rates of change in the chemistry of overburden and constructed soils.

7.1.4 Spoil-Soil-Plant Interactions

There is much that is unknown in this category, including the following points:

1. Plant growth relationships to water and nutrient supply.
2. Effect of soil depth, volume, or quality on root growth and function in mine/soil and natural soils.
3. Soil requirements for forage production or erosion control cover under the various site and climatic conditions of this region.

4. Distribution of plant nutrients by compartment and transfer rates between these in pre-mine and post-mine ecosystems.
5. Stress levels for various plant species on minesoils.
6. Effectiveness of plant-soil interactions in overcoming soil compaction problems and the level where compaction is a problem.
7. Importance of soil micro-organisms in plant rhizopheres in minesoils.
8. Extent and quantity of root exudates and sloughed root materials and importance to developing a stable system.
9. Necessity of adding mycorrhizae to minesoils.
10. Important mycorrhizal species.
11. Inoculation of plantings on minesoils.
12. pH tolerance levels of various plant species.
13. Vertical distribution of mycorrhizal inoculum.
14. Value of actinorhizal plant species in terms of the addition of nutrients.

7.1.5 Post-Reclamation Management

Information is lacking with regard to the following areas:

1. Methods and guidelines for monitoring ecosystem dynamics without sampling "the world."
2. Site protection measures.
3. Re-fertilization of site. If so, how often, how much, and when.

4. Land uses that can be made of a site and how soon.
5. Necessity of controlling vegetation competition.
6. Ways to encourage native species invasion.
7. When is a site "self-maintaining."

7.2 EVALUATION OF CURRENT RECLAMATION RESEARCH

Current and past research efforts can be grouped under four general approaches for the purpose of discussion:

1. Demonstration of plant establishment and survival.
2. Comparison of management methods.
3. Comparison of soil reconstruction methods.
4. Functional analysis of the soil-plant system.

Most research over the past 15 years has been primarily a demonstration of plant establishment and survival. Various revegetation materials have been planted on spoils in the Mountain-Foothills region and checked periodically for survival. Edaphic and other environmental variables usually have not been recorded for correlation with establishment or survival. These efforts have shown that vegetation can be established on some sites that were previously considered unsuitable, but lack of documentation limits extrapolation of the information.

Research efforts that are classified as a comparison of management methods include selection of revegetation species, seeding methods, effects of mulches or other surface treatments, and fertilizer trials. Monitoring of results typically involved measurement of vegetation yield or cover using demonstration plots or a replicated plot design, but environmental variables and soil quality characteristics usually have not been monitored. The studies have concentrated mainly on vegetation or management, but do not provide information of use in determining soil requirements and performance.

Comparison of soil reconstruction methods is currently being examined on research plots at five locations: Obed Mountain (Obed Mountain Coal Co.), Judy Creek (Esso Resources Ltd.), Smoky River (Smoky River Coal Ltd.), Bryan Mountain (Crowsnest Resources Ltd.), and Cadomin (Alberta Forest Service). These plots compare varying depths of topsoil over regolith or bedrock spoil on growth of tree seedlings or grasses. Other evaluations of minesoil quality and performance related to construction method have been made on reclaimed landscapes at Cardinal River Coal Ltd. (Hardy Assoc. 1981a, 1981b, 1983) and at Coal Valley (Luscar Ltd. file data). These studies usually have replicated plot design and monitor some soil quality characteristics and site and vegetation variables.

The functional analysis types of research relate soil-plant processes such as organic matter dynamics and nitrogen cycling to soil, vegetation, and management variables. No research results of this type are available for the Mountain-Foothills of Alberta. Organic matter-nutrient studies by Fyles (1980, 1984), and Ziemkiewicz (1979a, b, 1982) at the Westar Mining Ltd. site near Sparwood, B.C. are examples of this type of research, and their results may be applicable to Montane and southern Subalpine areas in Alberta. A study on long-term fertilization cycles has been initiated at Cadomin, but data are not yet available (S. Takyi, Alberta ENR, pers. comm.). This approach has the advantages of measuring soil-plant functions directly (rather than obtaining an indication of them from vegetation growth data) and being generally applicable to other areas.

There are no data available to relate erosion loss rates from minesoils to climatic, topographic, vegetation, or soil factors. A study has been initiated by R. Chopiuk (Coal Research Centre, pers. comm. 1985) to relate soil loss rates to topographic variables, but no data are available at this time. Some casual observations have been reported for reclaimed land at Smoky River and Cardinal River. No other research is being done.

7.2.1 Adaptability to Current Gaps

Research projects are often very difficult to modify in order to obtain information that they were not originally designed to provide. Usually such modifications compromise the statistical analysis in one way or another. Perhaps not enough individual plants were established, or there is not enough replication to satisfactorily cover the variability associated with the desired new information, perhaps the origin of the seed or seedlings is not appropriate, or any one of a myriad of other things compromises the scientific credibility of the research. The situation with the research plots in the Mountain-Foothills is no exception.

All of the reviewed research was established with set objectives appropriate to the particular project, to the level of effort, and to that time. Most of the research plots do not, however, appear to be amenable to modification sufficient to provide the information we feel it is most necessary to collect. To make the necessary modifications would significantly compromise the scientific credibility of the results.

The existing research plots should definitely not be ignored, but should be used to provide insight into improving the experimental design and objectives of any new research to be undertaken.

7.3 RECOMMENDATIONS AND FUTURE RESEARCH

Based on our review of existing literature and the identified information gaps, we feel there are a number of areas requiring additional research.

7.3.1 Spoil Placement and Grading

Further study required in this category includes the following:

1. Development of spoil characterization and classification criteria. The ability to characterize spoil in the field with confidence is important, and would be most useful in that planning changes could be quickly and efficiently made at the appropriate time.
2. Better integration of materials handling and topographic constraints with the planned reclamation landscapes. Materials handling is an integral part of the land surface shaping and soil construction process, and information is lacking.
3. Acceptable erosion levels. Quite logically there is concern about erosion; however, erosion is occurring around us all the time. There must be an acceptable level where concern is expressed if it is exceeded and where it has a lower priority if it is below the level. A better understanding is definitely required.
4. Effectiveness and comparative costs of erosion control techniques. There are many ways of controlling erosion, and information is required with respect to how well a job is done and at what cost.

7.3.2 Soil Preparation and Treatments

Key research topics in this area include the following:

1. Rootzone requirements for various plant species and plant communities based on the intended land use and productivity level (including commercial forest species).
2. Field studies of spoil versus topsoil as a plant growth medium.
3. The effect of time on the types and rates of chemical and physical changes in spoil and topsoil both in the stockpile and in place.
4. Assessment of the effects of various soil amendments such as peat, LFH material, and fertilizers on soil erosion, compaction, water infiltration (also retention and availability), soil structure, and nutrient availability.
5. Assessment of rock fragment mineralogy for potential nutrients, trace elements, and toxic elements, and the rate of weathering.
6. Evaluation of the value of topsoil as a seed or plant stock source.

7.3.3 Spoil-Soil-Plant Interactions

Some of the key research needs in this area include the following:

1. Determination of plant growth relationships to water and nutrient supply.
2. Evaluation of the distribution of plant nutrients by compartment and the transfer rates between compartments in pre- and post-mine ecosystems.
3. Determination of the effectiveness of plant-soil interactions in overcoming soil compaction problems and effects of compaction.
4. Soil micro-organisms (including mycorrhizae): (1) what is the vertical distribution of inoculum in pre- and post-mine soil, and (2) if minesoils require inoculation, how is it best achieved and with what species.

5. Assessment of the extent and quantity of root exudates and sloughed root materials and their importance in increasing organic matter levels and developing a stable soil system.
6. Evaluation of the contribution of actinorhizal plant species to the soil nutrient regime.

7.3.4 Post-Reclamation Management

Some of the research needs identified for this area include the following:

1. Determination of what management measures are necessary to attain a given land use and productivity level.
2. Establishment of suitable methods (and associated guidelines) for monitoring ecosystem dynamics without sampling everything.
3. Development of guidelines to assist in ascertaining when a site is self-maintaining.

GLOSSARY OF TERMS

Acid soil	- A soil having a pH of less than 6.5.
Aeration	- The process by which air in the soil is replaced by air from the atmosphere.
Aggregate	- A group of soil particles cohering so as to behave mechanically as a unit.
Alkaline soil	- A soil having a pH greater than 7.3.
Available plant nutrient	- That portion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants.
Available water	- That portion of water in a soil that can be readily absorbed by plant roots.
Bedrock overburden	- The in situ Jurassic, Cretaceous, and Tertiary-aged formations that occur above coal. This includes soft and hard bedrock formations prior to mining.
Bedrock spoil	- Bedrock material that has been mined and dumped. It may consist of hard fragments of varying size or may be soil-sized particles.
Blanket	- A mantle of unconsolidated materials thick enough to mask minor irregularities in the underlying unit but which still conforms to the general underlying topography.
Bulk density, soil	- The mass of dry soil per unit bulk volume.
Capability (land)	- An evaluation of land performance that focuses on the degree and nature of limitation imposed by the physical characteristics of a land unit on a certain use, assuming a management system.
Cation	- An ion carrying a positive charge of electricity. The common soil cations are calcium, magnesium, sodium, potassium, and hydrogen.
Cation exchange capacity (C.E.C.)	- A measure of the total amount of exchangeable cations that can be held by the soil. It is usually expressed in terms of millequivalents per 100 grams of soil.
Coarse fragments	- Rock or mineral particles greater than 2 mm in diameter.

Consistence	- (a) The resistance of a material to deformation or rupture; (b) the degree of cohesion or adhesion of the soil mass.
Consolidated bedrock	- Bedrock that is too hard to break with the hands (>3 on Moh's scale) or to dig with a spade when moist (lithic).
Coversoil	- Unconsolidated materials including salvaged Surface Soil, salvaged Regolith, or selected Bedrock Spoil used to top-dress spoils to build a better quality Minesoil.
Droughty soil	- Sandy or rapidly drained soil with low available moisture capacity.
Electrical conductivity (EC)	- The reciprocal of electrical resistivity. Expressed in milli-siemens per centimetre (mS/cm). EC provides a measure of water-soluble salt content.
Eluviation	- The removal of soil material in suspension or in solution form a layer or layers of the soil.
E/m^2	- Equivalents (1000 milliequivalents) per square metre of surface area.
Erosion	- The wearing away of the land surface by running water, wind, or other erosive agents. It includes both normal and accelerated soil erosion. The latter is brought about by changes in natural cover or ground conditions and includes those due to human activity.
Family particle size (soil)	- The particle-size classes for family groupings are as follows: Fragmental - Stones, cobbles and gravel, with too little fine earth to fill interstices larger than 1 mm. Sandy-skeletal - Particles coarser than 2 mm occupy 35% or more by volume with enough fine earth to fill interstices larger than 1 mm; the fraction finer than 2 mm is that defined for the sandy particle-size class.

Loamy-skeletal - Particles 2 mm - 25 cm occupy 35% or more by volume with enough fine earth to fill interstices larger than 1 mm; the fraction finer than 2 mm is that defined for the loamy particle-size class.

Clayey-skeletal - Particles 2 mm - 25 cm occupy 35% or more by volume with enough fine earth to fill interstices larger than 1 mm; the fraction finer than 2 mm is that defined for the clayey particle-size class.

Sandy - The texture of the fine earth includes sands and loamy sands, exclusive of loamy very fine sand and very fine sand textures; particles 2 mm - 25 cm occupy less than 35% by volume.

Loamy - The texture of the fine earth includes loamy very fine sand, very fine sand, and finer textures with less than 35% clay; particles 2 mm - 25 cm occupy less than 35% by volume.

Fertility - The status of a soil in relation to the amount and availability to plants of elements necessary for plant growth.

Fluvial deposits - All sediments, past and present, deposited by flowing water, including glaciofluvial deposits. Wave worked deposits and deposits resulting from sheet erosion and mass wasting are not included.

Frost-free period - Season of the year between the last frost of spring and the first frost of fall.

Frost heave - The raising of a surface caused by ice formation in the underlying soil.

Glacial drift - Or simply drift. The sediments deposited directly by glaciers (till) or indirectly in glacial streams, lakes and the sea (stratified drift).

Glaciofluvial deposits	- Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plains, deltas, kames, eskers, and kame terraces.
Glaciolacustrine deposits	- Materials moved by glaciers and subsequently deposited in a ponded water situation in contact with, or the result of, glacial ice.
Horizon (soil)	- A layer in the soil profile approximately parallel to the land surface with more or less well-defined characteristics that have been produced through the operation of soil forming processes. Soil horizons may be organic or mineral.
Hummocky moraine	- A landform composed of knobs and depressions with local relief generally in excess of 10 metres. Materials are mostly till some stratified drift may be included.
Humus forms	- The common terrestrial humus forms are mor, moder and mull. The common hydromorphic humus form is peaty mor.
Illuviation	- The process of deposition of soil material removed from one horizon to another in the soil, usually from an upper to a lower horizon in the soil profile. Illuviated compounds include silicate clays, iron and aluminum hydrous oxides and organic matter.
Infiltration	- The downward entry of water into the soil.
Lithic	- Hard, consolidated bedrock.
Minesoil	- Soil produced by mining and reclamation activities that is capable of supporting plant growth.
Moder	- Humus forms with partial to advanced mechanical intermixing of mineral soil and organic matter.
Mor	- Humus forms with diagnostic horizons (F + H) sharply delineated from the mineral soil. The H horizon is very thin or absent in fibrimor, but is dominant in humimor. Also called raw humus.
Morphology, soil	- The makeup of the soil, including the texture, structure, consistence, color, and other physical, mineralogical and biological properties of the various horizons of the soil profile.

Mull - Humus forms with intimate association of organic matter and mineral soil. F and H horizons lacking.

Organic soils - Soils formed from peat. The peat must be 40 cm thick or greater.

Overburden - Materials of any nature, consolidated or unconsolidated, that overlie a deposit of useful materials. In the present situation, overburden refers to the soil and rock strata which overlie coal deposits.

pH - See soil reaction.

Paralithic bedrock - Soft non-lithic bedrock, either unconsolidated or weathered enough to be dug with a shovel.

Parent material - Unconsolidated mineral material or peat from which the soil profile develops.

Peat - Unconsolidated soil material consisting largely of undecomposed to partially decomposed organic matter accumulated under conditions of excessive moisture.

Ped - A unit of soil structure such as a prism, block, or granule, formed by natural processes (in contrast to a clod, which is formed artificially).

Percolation, soil water - The downward movement of water through soil. Especially the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

Permeability - The ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil. Since different horizons of soil vary in permeability, the particular horizon under question should be designated.

Premine soil - A, B and C horizons to maximum depth of 1 m or to bedrock.

Productivity (land) - The physical yield expected from a land unit assuming specified management practices and input levels.

Profile - A vertical section of the soil throughout all its horizons and extending into the parent material.

Regolith	- Unconsolidated overburden that lies above bedrock. It includes glacial drift and colluvial and fluvial deposits that occur below the premine soil but does not include soft (paralithic) weathered-in-place bedrock.
Relief	- The elevations or inequalities of the land surface when considered collectively. Minor configuration are referred to as "microrelief".
Seepage (groundwater)	- The emergence of water from the soil over an extensive area in contrast to a spring where it emerges from a local spot.
Soil	- (a) The collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials containing living matter and supporting or capable of supporting plants out-of-doors. (b) Unconsolidated mineral or organic materials.
Soil reaction	- The degree of acidity or alkalinity of a soil, usually expressed as a pH value. Descriptive terms commonly associated with certain ranges in pH are: extremely acid, <4.5; very strongly acid, 4.5-5.0; strongly acid, 5.1-5.5; moderately acid, 5.6-6.0; slightly acid, 6.1-6.5; neutral, 6.6-7.3; slightly alkaline, 7.4-7.8; moderately alkaline, 7.9-8.4; strongly alkaline, 8.5-9.0; and very strongly alkaline, >9.0.
Soil structure	- The combination or arrangement of primary soil particles into secondary particles, units, or peds. The secondary units are characterized and classified on the basis of size, shape, and degree of distinctness into classes, types and grades.
Solum (plural-sola)	- The part of the soil profile that is above the parent material and in which the processes of soil formation are active. It comprises the A and B horizons.
Spoil	- (1) The overburden or non-ore material removed in gaining access to the ore or mineral material in surface mining. (2) Debris or waste material from a mine.
Spoil pile	- A pile of spoiled overburden on a minesite.

Subsoil	- Technically, the B horizon; broadly, the part of the profile below plow depth.
Surface Soil	- The premine (undisturbed) soil profile, made up of any or all of the litter layer, and A, B and BC horizons; or organic horizons (including deep peat deposits).
Texture (soil)	- The relative proportions of the various-sized soil separates in a soil as described by the textural class names.
Till	- Unstratified glacial drift deposited directly by ice and consisting of nonsorted clay, silt, sand and boulders.
Topsoil	- (1) The layer of soil moved in cultivation. (2) The A horizon. (3) The Ah horizon. (4) Favorable soil materials used to cover mine spoils.
Veneer	- A mantle of unconsolidated materials too thin to mask the minor irregularities of the underlying unit surface. A veneer will generally be less than 1 m in thickness.
Water-holding capacity	- The ability of soil to hold water. The waterholding capacity of sandy soils is usually considered to be low while that of clayey soils is high.
Watertable	- The upper limit of the soil or underlying rock material that is wholly saturated with water.
Weathering	- The physical and chemical disintegration, alteration, and decomposition of rocks and minerals at or near the earth's surface by atmospheric agents.

REFERENCES

Aber, J.D. and J.M. Melillo. 1980. Litter decomposition: measuring relative contributions of organic matter and nitrogen to forest soils. Can. J. Botany 58:416-421.

Alberta Energy and Natural Resources. 1979. Alberta Land Inventory. Land Capability Classification for Forestry. ENR Report No. 111.

Alberta Energy Resources Conservation Board (ERCB). 1984. Reserves of Coal, Province of Alberta (9th Edition) Issued Annually. ERCB ST 84-31. Report plus maps.

Alberta Land Conservation and Reclamation Council (LCRC). 1977. Guidelines for the reclamation of land affected by a surface disturbance. Alberta Env. and Alberta ENR.

Alberta Soils Advisory Committee. 1981. Proposed soil quality in relation to disturbance and reclamation. Soil Quality Criteria Subcommittee (Stage II). Alberta Agric.

Allen, E.B. and M.F. Allen. 1980. Natural re-establishment of vesicular-arbuscular mycorrhizae following stripmine reclamation in Wyoming. J. of Applied Ecology 17:139-147.

Anderson, J. P. Ineson and S. Huish. 1983. Nitrogen and cation mobilization by soil fauna feeding on leaf litter and soil organic matter from deciduous woodlands. Soil Biol. Biochem. 15:463-467.

Anderson, J.E. and S.J. McNaughton. 1973. Effects of low soil temperature on transpiration photosynthesis, leaf relative water content, and growth amoung elevationally diverse plant populations. Ecol. 54(6):1220-1233.

Annas, R.M., S.L. Robertson, J.A. Bentz and Z.J. Nemeth. 1983. An ecosystem classification of the Boreal Cordilleran Ecozone: Sundre area. Res. Branch, Alta. For. Serv. ENR. REAP. ENR. Edmonton, Alta.

Arkley, R.J. 1981. Soil moisture use by mixed conifer forest in a summer-dry climate. Soil Sci. Soc. Am. J. 45:423-427.

Armson, K.A. 1980. Tree rooting characteristics. IN: Workshop on reconstruction of forest soils in reclamation. Alberta Land Cons. and Reclamation Council, Edmonton, Alberta. RRTAC Report No. 80-4. pp.2-8.

Ashby, W.C., W.C. Vogel, C.A. Kolar and G.R. Philo. 1984. Productivity of stony soils on stripmines. pp. 31-44. IN: ERosion and Productivity of Soils Containing Rock Fragments. SSSA Spec. Pub. No. 13, Soil Sci. Soc. of America, Madison, Wis. 103 pp.

Baig, M.N. 1972. Ecology of timberline vegetation in the Rocky Mountains of Alberta. Ph.D. thesis, Dept. of Biology, Univ. of Calgary, Calgary, Alberta. 444 pp.

Ballard, T.M. 1980. Tree nutrition. IN: Proceedings: Workshop on reconstruction of forest soils in reclamation. Alberta Land Conservation and Reclamation Council. Report #RRTAC 80-4.

Barber, D.A. 1968. Microorganisms and the inorganic nutrition of higher plants. Ann. Rev. Pl. Physiol. 19:71-88.

Barnes, K.K., W.M. Carleton, H.M. Taylor, R.I. Throckmorton and G.E. Vaden Berg (eds.). 1971. Compaction of agricultural soils. Am. Soc. Agric. Eng. Monograph, St. Joseph, MO. 471 pp.

Barnett, A.P., E.G. Diseker, and E.C. Richardson. 1967. Evaluation of mulching methods for erosion control on newly prepared and seeded highway backslopes. Agronomy J. 59(1):83-85.

Barth, R.C. 1984. Soil-depth requirements to reestablish perennial grasses and surface-mined areas in the Northern Great Plains. Mineral and Energy Resources. A Review of Developments. Vol. 27. No. 1.

Berg, W.A. and E.M. Barrau. 1978. Management approaches to nitrogen deficiency in revegetation of subalpine disturbances. IN: Proceedings: High-altitude disturbed lands. Colorado State Univ. Infor. Series No. 10. pp. 174-181.

Bertsch, M. and F. Osterwoldt. 1984. Vegetation of survey of reclamation plots at Obed. File No. 84-30, Western Reclamation Services.

Billings, W.D. 1979. Alpine ecosystems of western North America. IN: Special Management Needs of Alpine Ecosystems. Society for Range Management. Peerless Printing, Denver, Colo. pp. 6-21.

Biodini, M.E. and E.F. Redente. 1983. Suitability and diversity in disturbed land reclamation. Abstract of Paper at 36th Annual Meeting. Soc. Range Manage., Albuquerque, N.M.

Black, C.A. 1968. Soil-plant relationships. John Wiley & Sons, New York. 792 pp.

Borovsky, J.P. 1979. Natural revegetation of iron mining overburden. IN: Proceedings of the 1979 Meeting of the Mineral Waste Stabilization Liaison Committee, D.G. Youngman (ed.). Eveleth, Minnesota.

Bouma, J. and J.L. Anderson. 1973. Relationship between soil structure characteristics and hydraulic conductivity. IN: Field Soil Water Regime. Soil Sci. Soc. Amer. Madison, Wis. Spec. Pub. No. 5 pp. 77-105.

Bowen, G.D. and A.D. Rovira. 1976. Microbial colonization of plant roots. Ann. Rev. Phytopath. 14:121-144.

Brocke, L.K. 1981a. Comparison of topsoil and regolith materials at the Cardinal River mine site. Prep. for Cardinal River Coals Ltd. by Western Soil Environmental Services. 13 pp.

Brocke, L.K. 1981b. Soil survey, overburden characterization and interpretations for reclamation for the Obed Mine area. Prep. by Western Soil and Environmental Services for Union Oil Co. of Canada Ltd. 85 pp.

Brocke, L.K. 1981c. Detailed soil survey and overburden characterization of the Gregg River five year mine area and interpretations for reclamation. Prep. for Gregg River Resources Ltd. by Western Soil and Environmental Services. 38 pp.

Brocke, L.K. and A.G. Twardy. 1976a. Detailed soil survey and interpretations for the 50-A-3 area. Prep. for Cardinal River Coals Ltd. by Pedology Consultants. 13 pp. plus append.

Brocke, L.K. and A.G. Twardy. 1976b. Detailed soil survey and interpretations for the 51-C-1 pit area. Prep. for Cardinal River Coals Ltd. by Pedology Consultants. 16 pp. plus append.

Brocke, L.K. and A.G. Twardy. 1978. Detailed soil survey of the Luscar Freehold area and interpretations for reclamation. Prep. for Cardinal River Coals Ltd. by Pedology Consultants. 81 pp.

Brown, R.W. and R.S. Johnston. 1979. Revegetation of disturbed alpine rangelands. pp. 76-94. IN: Special Management Needs of Alpine Ecosystems, D.A. Johnson (ed.). Symposium Proc., Soc. for Range Management. Range Science Series No. 5. Peerless Printing, Denver, Colo.

Bussler, B.H., W.R. Byrnes, P.E. Pope, and W.R. Chaney, 1984. Properties of minesoil reclaimed for forest land use. Soil Sci. Soc. Am. J. 48:178-184.

Cairns, J., Jr. 1983. Management options for rehabilitation ad enhancement of surface-mined ecosystems. Minerals and the Environment 5:32-38.

Campbell, C.A., and W. Souster. 1982. Loss of organic matter and potentially mineralizable nitrogen from Saskatchewan soils due to cropping. Can. J. Soil Sci. 62:651-656.

Carrel, J.E., C.L. Kucera. A.P. Harrison, C.J. Johannsen and R.W. Blancher. 1982. Strip-mine reclamation: Criteria and methods for measurement of revegetation success. Final Report for period June 1, 1975 - September 30, 1982. U.S. Department of Energy, Washington, D.C. Report No. DOE/EV/02758-8. 21 pp.

Carter, F.S. and E.C. Doll. 1983. Reclaiming prime soils. Reclam. Res. Summaries. USDA and N. Dakota State Univ. Land Recl. Res. Cent. pp. 24-30.

Cary, J.W. and C.W. Hayden. 1973. An index to pore size distribution. Geoderma 9:249-256.

Cassman, K.G. and D.N. Munns. 1980. Nitrogen mineralizatioln as affected by soil moisture, temperature and depth. Soil Sci. Soc. Amer. J. 44:1233-1237.

Chapin, F.S. and M.C. Chapin. 1981. Ecotypic differentiation of growth processes in Carex aquatilis along latitudinal and local gradients. Ecology, 62(4):1000-1009.

Childs, E.C. 1969. The physical basis of soil water phenomena. John Wiley and Sons, New York.

Clark, M.B. and McLean. 1975. Growth of lodgepole pine seedlings in competition with different densities of grass. B.C. For. Serv. Res. Note No. 70. 10 pp. illus.

Clayton, J.L. 1979. Nutrient supply to soil by rock weathering. pp. 75-96. IN: Impact of Intensive Harvesting on Forest Nutrient Cycling. Proceedings of Symposium at the State Univ. of New York, Aug. 13-16. 1979. Northeast Forest Exp. Sta., USDA Forest Service, Broomall, Penn.

Cochran, P.H. 1969. Thermal properties and surface temperatures of seedbeds. Pac. Nor. For. and Rng. Exp. Stn., U.S. Dept. of Agr. Portland, Oregon. 19 pp.

Cochran, P.H. 1975. Soil temperatures and natural forest regeneration in south-central Oregon. pp. 37-52 IN: Forest soils and forest land management. B. Bernier and C.H. Winget (eds.). Les Presses De L'Universite Laval, Laval, Quebec. 675 p.

Cochrane, C.E. and H.S. McNabb, Jr. 1979. Aluminum and pH effects on growth and mycorrhizal relationships in Pisolithus tinctorius. (Abstract). IN: Proc. Fourth North Amer. Conf. on Mycorrhiza. Colorado State University. Ft. Collins, Colorado. p. 41.

Coen, G.M. and W.D. Holland. 1976. Soils of Waterton Lakes National Park, Alberta. Alberta Institute of Pedology. S-73-33.

Cole, D.W., S.P. Gessel and S.F. Dice. 1967. Distribution and cycling of nitrogen, phosphorus, potassium and calcium in a second-growth Douglas-fir ecosystem. IN: Symposium on primary productivity and mineral cycling in natural ecosystems. Univ. of Maine Press, Orono. pp. 197-232.

Comerford, N.B., G. Kidder and A.V. Mollitor. 1984. Importance of subsoil fertility to forest and non-forest plant nutrition. IN: Proceedings of the Sixth North American Forest Soils Conference. Dept. of Forestry, Wildlife and Fisheries. Univ. of Tennesse. pp. 381-404.

Cook, C.W.and C.D. Bonham. 1977. Techniques for vegetation measurements and analysis for a pre- and postmining inventory. Colorado State Univ. Range Sci. Dept., Science Series No. 28. Col. State Univ., Fort Collins, Col. 94 pp.

Corns, I.G.W. 1978. Tree growth predicting and plant community distribution in relation to environmental factors in lodgepole pine, white spruce, black spruce and aspen forests of western Alberta foothills. Unpubl. Ph.D. thesis. Dept. of Soil Sci., Univ. of Alta. 229 pp.

Corns, I.G.W. and P.L. Achuff. 1982. Chapter III - Vegetation. pp. 71-156. IN: W.D. Holland and g.m. coen (eds.). Ecological (biophysical) land classification of Banff and Jasper National Parkis. Vol. II: Soil and Vegetation Resources. Alberta Institute of Pedology, Univ. of Alberta, Edmonton. Publ. No. 55-82-44.

Cox, T.L. and S.G. Witter. 1978. Applications of remote sensing technology to disturbed lands. IN: Reclamation of Drastically Disturbed Lands. American Society of Agronomy, Madison, Wisconsin. USA. pp. 705-727.

Crocker, R.L. 1960. The plant factor in soil formation. Proc. 9th Pacific Sci. Congr. of Pacific Sci. Assn. 18:84-90.

Crocker, R.L. and J. Major. 1955 Soil development in relation to vegetation and surface age at Glacier Bay, Alaska. J. Ecol. 43:427-448.

Dahlman, R.C. and C.L. Kucera. 1965. Root productivity and turnover in Native prairie. Ecology 46:84-89.

Dale, M.E. 1963. Interplant alder to increase growth in strip-mine plantations. USDA For. Serv. Res. Note CS-14. 4 pp.

Damman, A.W.H. 1971. Effect of vegetation changes on the fertility of a Newfoundland forest site. Ecol. Monographs 41:253-270.

Dancer, W.S., J.F. Handley and A.D. Bradshaw. 1977a. Nitrogen accumulation in kaolin mining wastes in Cornwall. 2. Forage legumes. Plant Soil 48:303-314.

Dancer, W.S., J.F. Handley and A.D. Bradshaw. 1977b. Nitrogen accumulation in kaolin mining wastes in Cornwall. 2. Forage legumes. Plant Soil 48:303-314.

Danielson, R.M., C. Griffiths and D. Parkinson. 1984. Reinstatement of biological activity in severly disturbed soils: ectomycorrhizae in amended oil sand tailings and subalpine coal mine spoil and in undisturbed jack pine and spruce stands. IN: Soil Microbiology in Land Reclamation. Vol. II. Mycorrhizae. Alberta Land Conservation and Reclamation Council Rept. RRTAC 84-4, 97 pp.

Danielson, R.M., S. Visser and D. Parkinson. 1983a. Microbial activity and mycorrhizal potential of four overburden types used in the reclamation of extracted oil sands. Can. J. Soil Sci. 63:363-375.

Danielson, R.M., S. Visser and D. Parkinson. 1983b. Plant growth in four overburden types used in the reclamation of extracted soil sand. Can. J. Soil Sci. 63:353-361.

Darby, S.P. 1980. A look at trees and reclamation in Georgia. IN: Proceedings, Trees for Reclamation, Lexington, Kentucky. Interstate Mining Compact comm. and USDA Forest Service. Gen. Tech. Rep. NE-61. pp. 11-14.

Daubenmire, R.F. 1943. Vegetational zonation in the Rocky Mountains. The Botanical Review. Vol. IX, No. 6:325-393.

Day, R.J. 1964. The micro-environments occurpied by spruce and fir regeneration in the Rocky Mountains. Dept. For. Res. Publ. No. 1037.

Day, R.J. and J. Skoupy. 1971. Moisture storage capacity and post-planting patterns of moisture movement from seedling containers. Can. J. of For. Res. 1:151-158.

Dempster, W.R. 1981. The response of pine and white spruce yields to silvercultural treatments in Alberta. A review of present knowledge and research priorities. Alberta Forest Service Report.

Dempster, W.R. 1985. Reforestation field trials on Obed-Marsh simulated mining sites. Progress report for 1984. Report for Union Oil Co. of Canada Ltd.

Dempster, W.R. and K.O. Higginbotham. 1985. Mountain/Foothills Reclamation Research Program: growth performance of commercial timber species. Prepared by W.R. Dempster & Associates Ltd. for Alta. Env. Res. Management Div. and The Coal Assn. of Canada. 86 pp.

Dejong. R., C.A. Campbell and W. Nicholaichuk. 1983. Water retention equations and their relationship to soil organic matter and particle size distribution for disturbed samples. Can. J. Soil Sci. 63:291-302.

Development and Reclamation Review Committee. 1984. Guidelines for coal mine development and reclamation application. Draft guidelines, May 1984. Alberta D&R Comm. 25 pp.

Doll, E.C., G.A. Halvorson and S.A. Schroeder. 1983. Reestablishing productivity on reclaimed soils. IN: Can mined lands be made better than before mining? Land Reclamation Res. Center (NDSU). N. Dakota Mining and Mineral Resources Res. Inst. (UND) and N. Dakota Energy Development Impact Office, Bismark, N. Dakota. pp. 77-84.

Doll, E.C., G.A. Halvorson, S.A. Schroeder and N.C. Woolenhaupt. 1983. Reclamation research in North Dakota. North Dakota Farm Research 41(4):36-39.

Doll, E.C., N.C. Wollenhaupt, G.A. Halvorson and S.A. Schroeder. 1984. IN: Third Biennial Symposium on Surface Coal Mine Reclamation on the Great Plains. Billings, Montana. pp. 88-101.

Dowdell, R.J., K.A. Smith, R. Crees and S.W.F. Restall. 1972. Field studies of ethylene in the soil atmosphere-equipment and preliminary work. Soil Biol. Biochem. 4:325-332.

Down, C.G. 1975. Soil development on colliery waste tips in relation to age. J. Appl. Ecol. 12:617.

Duffy, P.J.F. 1965. Relationships between site factors and growth of lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) in the foothills section of Alberta. Can Dept. For. Pub. No. 1065. 60 pp.

Dumanski, J., T.M. Macyk, C.F. Veauvy, and J.D. Lindsay. 1972. Soil survey and land evaluation of the Hinton-Edson area, Alberta. Alta. Inst. of Pedology. Report No. S-72-31.

Dumanski, J., J.C. Wright, and K.D. Lindsay. 1973. Evaluating the productivity of pine forests in the Hinton-Edson area. Alberta, from soil survey Maps. Can. J. Soil Sci. 53:405-419.

Ehler, W.L. 1963. Water absorption of alfalfa as affected by low root temperature and other factors of a controlled environment. Agron. J. 55: 363-366.

Eis, S. 1970. Root-growth relationships of juvenile white spruce, alpine fir, and lodgepole pine on three soils in the interior of British Columbia. Can. For. Serv. Publ. 1276.

Energy Resources Conservation Board (Alberta). 1983. Map. Major coal-bearing formations in Alberta. Single sheet Map, ERCB, Calgary.

Energy Resources Conservation Board (Alberta). 1984. Reserves of coal, Province of Alberta. ERCB Report 84-31. Updated Annually, ERCB, Calgary.

Esso Minerals Canada Ltd. 1979. Final Reclamation Plan: Judy Creek Test Pit. Unpublished report submitted to Alberta Energy and Natural Resources. 85 pp.

Esso Resources Canada Ltd. 1984. Judy Creek test mine reclamation studies. Annual report describing 1979 to 1984 study. Submitted in accordance with D & R approval. No. C-4-78.

Etter, H.M. 1969. Growth, metabolic components and drought survival of lodgepole pine seedlings at three nitrate levels. Can. J. Plant Sci. 49(4):393-402.

Etter, H.M. 1971. Preliminary report of water quality measurements and revegetation trials on mined land at Luscar, Alberta. Northern Forest Research Centre, Can. For. Serv., Environment Canada, Edmonton, Albertqa. 19 p.

Fabro, E.W. and D. Kittleson. 1983. Reclamation activities in Alberta by Crows Nest Resources Ltd. IN: Proceedings, Second Alberta Reclamation Conference. Edmonton, Alberta. Alta. Chapter CLRA. Pub. No. CLRA/AC 83-1.

Farmer, E.E. and J.E. Fletcher. 1976. Highway erosion control systems: An evaluation based on the universal soil loss equation. IN: The Proceedings of a National Conference on Soil Erosion. Purdue University, West Lafayette, Indiana pp. 12-21.

Farmer, E.E. and B.Z. Richardson. 1976. Hydrologic and soil properties of coal mine overburden piles in southeastern Montana. IN: Proceedings of Fourth Research and Applied Technology Symposium, Louisville, Kentucky. pp. 120-130.

Fedkenheuer, A.W. 1969. Soil profile descriptions, St. Croix State Park. Unpublished data.

Fedkenheuer, A.W. 1975. Past and present forest communities of St. Croix State Park, Minnesota, and their use in determining erncomanagement direction. Ph.D. thesis, Univ. of Minn., Minneapolis, Minn. 338pp.

Fedkenheuer, A.W. 1980. Soil building research at Syncrude using selected mineral soil materials. pp. 22-48 IN: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation, Ziemkiewicz, P.F., S.K. Takyi and H. Regier (eds.). Alberta Land Conservation and Reclamation Council Report RRTAC 80-4, Edmonton, Alta. 160 pp.

Fessenden, R.J. 1979. Use of actinorhizal plants for land reclamation and amenity planting in the U.S.A. and Canada. IN: Symbiotic Nitrogen Fixation in the Management of Temperate Forests. pp. 403-419. Editor J.C. Gordon et al. Oregon State University, Covallis, Oregon.

Feustel, I.C. and H.G. Byers. 1930. The physical and chemical characteristics of certain American peat profiles. U.S.D.A. Tech. Bull. 214. U.S.D.A. Washington, D.C.

Fitter, A.H. 1977. Influence of mycorrhizal infection on competition for phosphorus and potassium by two grasses. New Phytologist 79:119-125.

Frazier, B.E., D.K. McCool, and C.F. Engle. 1983. Soil erosion in the Palouse: An aerial pe3rspective. IN: Journal of Soil & Water Conservation. 38(2):70-74.

Froehlich, H.A. and D.H. McNabb. 1984. Minimizing soil compaction in Pacific Northwest Forests. IN: Proc. of the Sixth North American Forest Soils Conference. Dept. of Forestry, Wildlife and Fisheries. Univ. of Tennessee. pp. 159-192.

Fyles, H. 1984. Nitrogen cycling through soil-plant systems on high elevation reclaimed mine sites (unpubl.). Master thesis, Univ. of Alberta, Edmonton. 133 pp.

Fyles, J.W. 1980. Vegetation and development on reclaimed mine lands at high elevation in south eastern British Columbia. Unpubl. M.Sc. Thesis. Dept. of Biol., University of Victoria. 71 pp.

Fyles, J.W., I.H. Milne and M.A.M. Bell. 1982. Development of vegetation and soil on high elevation reclaimed lands in southeastern B.C. IN: Reclamation in mountainous Areas. Proceedings of the Sixth Annual Meeting of the CLRA and Fifth Annual B.C. Mine Reclamation Symp., Cranbrook. B.C. Min. of Energy, Mines and Petr. Res., Inspection and Eng. Branch, Victoria, B.C. Paper 1982-2, pp. 221-236.

Gardiner, R.T. and Stathers. 1979. Phosphorus requisite for legume-dominated vegetation on mine wastes. IN: Reclamation of Lands Disturbed by Mining. Proceedings of the Third Annual British Columbia Mine Reclamation Symposium. Vernon, B.C., Mar. 7-9, 1979. B.C. Min. of Energy, Mines and Petroleum Resources, Inspection & Eng. Div., Victoria, B.C. Paper 1979-4. pp. 221-238.

Gautier, C.R. 1983. The effects of ryegrass on erosion and natural vegetation recovery after fire. IECA Report, Vol. 15(1):3-4.

Gee, G.W., J.E. Gilley and A. Bauer. 1976. Use of soil properties to estimate soil loss by water erosion on surface-mined lands of Western North Dakota. Farm Research. pp. 40-43.

Geiger, R. 1965. The climate near the ground. Harvard University Press, Cambridge, Massachusetts. 611 pp.

Gerrard, A.J. 1981. Soils and landforms. George Allen, and Unwin Publishers, London, England. 219 pp.

Gessel, S.P., D.W. Cole and E.C. Steinbrenner. 1973. Nitrogen balances in forest ecosystems of the Pacific Northwest. Soil Biol. Biochem. 5:13-34.

Gholz, H.L. and R.F. Fisher. 1982. Organic matter production and distribution in slash pine plantation ecosystems. Ecology 63:1827-1839.

Gholz, H.L. and R.F. Fisher. 1984. The limits to productivity: fertilization and nutrient cycling in coastal plain slash pine forest. IN: Proc. of the Sixth North American Forest Soils Conference. Dept. of Forestry, Wildlife and Fisheries. Univ. of Tennessee. pp. 105-120.

Gibson, D.W. 1979. The Morrissey and Mist Mountain Formations - newly defined lithostratigraphic units of the Jura-Cretaceous Kootenay Group. Alberta and British Columbia; Bulletin of Canadian Petroleum Geology. 27(2):183-208.

Gill, W.R. 1961. Mechanical impedance of plants by compact soils. Trans. Am. Soc. Agric. Eng. 4:238-342.

Grant, W.J., C.D. Stanley, G.R. Benoit, and D.B. Torrey. 1983. Seeding rate recommendations for a winter rye cover crop based on expected leaf area index. J. Soil and Water Conservation July-Aug. pp. 361-363.

Green, B. 1980. Reclamation biology--succession and the determination of successful reclamation. IN: Proceedings of the Workshop on Rehabilitation of Disturbed Arid Lands. Utah State Univ., Logan, Utah. pp. 82-88.

Green, J.E., R.E. Salter and D.G. Walker. 1985. Reclamation of wildlife habitat in the mountain and foothills biomes of Alberta. LGL Limited report to Mountain-Foothills Reclamation Research Program. 194 pp. plus appendices.

Grossnickle, S.C. and C.P.P. Reid. 1982. The use of ecotomycorrhizal conifer seedlings in the revegetation of a high-elevation mine site. Can. J. For. Res. 13:1145-1158.

Grossnickle, S.C. and C.P.P. Reid. 1984a. Water relations of Engelmann spruce seedlings on a high-elevation mine site: an example of how reclamation techniques canalter microclimate and edaphic conditions. Reclamation Reveg. Res. 3:199-221.

Grossnickle, S.C. and C.P.P. Reid. 1984b. The influence of reclamation practices on the microclimate of a high-elevation mine site, and their effect on water relation patterns of Pinus contorta seedlings. Reclamation Reveg. Res. 3:31-48.

Gulf States Paper Corporation, Erosion Control Systems Business and Desert Sunshine Exposure Tests, Inc. 1976. Hold/Gro Micro Environment Test. Technical Bulletin 1-76. 7 pp.

Haaland, R.L., C.B. Elkins, C.S. Haveland and R. Rodriguez-Kabana. 1977. Genetic variability for root size in tall fescue. IN: Proceedings of the 24th Grass Breeders Work Planning Conference. Tifton, Georgia. 9 pp.

Hall, A. and W.A. Berg. 1983. Prediction of sodium hazard in coal mine overburden. Recl. and Reveg. Res. 2:191-204.

Hamburg, S.P. 1984. Effects of forest growth on soil nitrogen and organic matter pools following release from subsistence agriculture. IN: 6th North American Forest Soils Conference. pp. 145-158. E.L. Stone, Editor. Univ. of Tenn., Knoxville, Tenn.

Harapiak, J.T. and N.A. Flore. 1984. Behaviour of fertilized mixed forage stands. IN: Proceedings of the 21st Annual Alberta Soil Science Workshop. Edmonton, Alberta. pp. 256-263.

Hardy Associates (1978) Ltd. 1981a. Evaluation of reclamation at the Luscar open pit mine. Report prepared for Cardinal River Coals Ltd. 81 pp.

Hardy Associates (1978) Ltd. 1981b. Reclamation monitoring at the Luscar open pit mine, 1981 report. Report prepared for Cardinal River Coals Ltd. 24 pp.

Hardy Associates (1978) Ltd. 1983. Reclamation monitoring at the Luscar open pit mine, 1982 report. Report prepared for Cardinal River Coals Ltd. 47 pp.

Harris, R.F., O.N. Allen, and G. Chesters. 1966. Microbial colonization of soil aggregates as affected by temperature. Plant and Soil XXV, No. 3. pp. 361-371.

Harrison, A.E. 1977. Phosphorus cycles of forest and upland grassland ecosystems and some effects of land management practices. pp. 175-193 IN: Phosphorus Cycles of Ecosystems. Proc. of Symp. on Phosphorus in the Environment - It's Chemistry and Biochemistry. Institute of Terrestrial Ecology.

Harrison, J.E. 1977. Summer soil temperature as a factor in revegetation of coal mine waste. Geological Survey of Canada, Ottawa, Ontario. Paper 77-1A. Report of Activities, Part A. pp. 329-332.

Harrison, S.E. 1974. Some basic data with respect to coal mine waste reclamation. IN: Proceedings of Workshop on Reclamation of Disturbed Lands in Alberta. Edtn, Alta. Nor. For. Res. Cent. pp. 30-36.

Headdon, D.K. 1980. Physical site characteristics of abandoned coal mine spoil heaps: York Creek Mine, Coleman, Alberta. M.Sc. Thesis. Dep. Geography, Univ. Calgary, Calgary. 182 pp.

Hermesh, R. and L.M. Cole. 1983. Propagation study: Use of shrubs for Oil Sands mine reclamation. Rep. No. PSESG-RRTAC 84-2. Alberta Land Conservation and Reclamation Council. 58 pp.

Hillel, D. 1971. Soil and water. Physical principles and processes. Academic Press, New York. 288.

Hirvonen, H.E. 1976. Bowan Island, a landscape analysis. Pac. For. Res. Cent., Infor. Rep., BL-X-122, Victoria, B.C. 29 pp.

Holland, W.D. and I.G.W. Corns. 1980. Forest-soil relationships in western Alberta and reconstruction of forest soils in reclamation. IN: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. Alberta Land Conservation and Reclamation Council, Recl. Res. Tech. Advisory Committee (RRTAC). Edtn., Alberta. Report No. RRTAC 80-4. pp. 60-73.

Holland, W.D. and G.M. Coen (eds.). 1982. Ecological (biophysical) land classification of Banff and Jasper National Parks. Alta. Inst. Pedology Pub. No. SS-82-44. Univ. of Alberta, Edmonton.

Holmes, J.R.B. and D. Tackle. 1982. Height growth of lodgepole pine in Montana related to soil and stand factors. Montana State Univ., For. Sch. Bull. No. 21. 12 pp.

Horton, K.W. 1958. Rooting habits of lodgepole pine. Can. Dept. Nor. Aff. and Nat. Res., For. Br., For. Res. Div. Tech. Note No. 67. 26 pp.

Indorante, S.J., I.J. Jansen and C.W. Boast. 1981. Surface mining and reclamation: Initial changes in soil character. J. Soil and Water Cons. 36:347-351.

Islam, M.R. and S.K. Takyi. 1984. Cadomin reclamation research project third, fourth and fifth-year results. Alberta Forest Service, Alta. Dept. ENR. Edtn., Alta. ENR Tech. Rep. No. T/56. 50 pp.

Jacques, D., 1977. The capabilities of high-flight aerial photography and LANDSAT multispectral imagery for monitoring coal reclamation activity. IN: Proceedings of Coal Industry Reclamation Symposium. Banff, Alberta, February 13-16, 1977. Coal Association of Canada, Calgary, Alberta. pp. 17-26.

Jerykiewicz, T. and J.R. McLean. 1980. Lithostratographical and sedimentological framework of coal-bearing Upper Cretaceous and Lower Tertiary strata, Coal Valley area, Cen. Alta. Foothills. Geol. Surv. Can. Pap. 79-12. 47 pp.

Johnson, E.A. 1980. Trees for tomorrow. IN: Trees for Reclamation. USDA Forest Service. Lexington, Kentucky. Gen. Tech. Rep. NE-61. pp. 1-6.

Johnson, M.S., T. McNeilly and P.D. Putwain. 1977. Revegetation of metalliferous mine spoil contaminated by lead and zinc. Environmental Pollution 12(4):261-277.

Johnson, R.L. 1985. Managing salts in sodic materials. IN: Proceedings of the 22nd Annual Alberta Soil Science Workshop, Lethbridge, Feb. 1985. pp. 122-129.

Johnson, R.L., P.J. Burton, B. Klaassan, P.D. Lulman and D. Doram. 1984. Reclamation monitoring: The critical elements of a reclamation monitoring program program in Wester North America. IN: Proceedings of the Ninth Annual Meeting, Canadian Land Reclamation Assoc. Calgary, Alberta.

Jorgenson, J.R., C.G. Wells and L.T. Metz. 1980. Nutrient changes in decomposing loblolly pine forest floor. Soil Sci. Soc. Am. J. 44:1307-1314.

Jurgensen, M.F. 1973. Relationship between nonsymbiotic nitrogen fixation and soil nutrient status - a review. J. Soil Sci. 24:512-522.

Jurgensen, M.F. 1978. Microorganisms and the reclamation of mine wastes. IN: Forest Soils and Land Use. Proc. 5th N. Amer. Forest Soils Conf. Ft. Collins, Colorado. pp. 251-286.

Kay, B.L. 1978. Mulches for erosion control and plant establishments on disturbed sites. IN: Proceedings of the Third High Altitude Revegetation Workshop, Col. State Univ., Ft. Collins, Co. 19 pp.

Kay, B.L. 1983. Straw as an erosion control mulch. Agronomy Progress Report. Agr. Exp. Stn. Cooperative Ext. No. 140. Univ. of Cal., Davis. 11 pp.

Keeney, D.R. 1980. Prediction of soil nitrogen availability in forest ecosystems: a literature review. Forest Sci. 26:159-171.

Kennedy, A. 1984. Effects of replaced surface soil depth on reclamation success at the Judy Creek test mine. IN: 1984 Canadian Land Reclamation Assoc. 9th Annual Meeting. Calgary, Alberta.

Kimmins, J.P. and B.C. Hawkes. 1978. Distribution and chemistry of fine roots in a white spruce-subalpine fir stand in British Columbia: Implications for management. Can. J. For. Res. 8:265-279.

Kirby, C.L. 1974. Remote monitoring of environmental change. (Summary). IN: Proceedings of Workshop on Reclamation of Disturbed Lands in Alberta. Edmonton, Alberta, March 27-28, 1974. Editors D. Hocking and W.R. MacDonald. Information Report NOR-X-116. pp. 13-14.

Kleinman, L.H. 1984. Industry's view of reclamation/revegetation success. IN: Third Biennial Symposium on Surface Coal Mine Reclamation on the Great Plains. Billings, Montana. pp. 335-341.

Klock, G.O. 1982. Some soil erosion effects on forest soil productivity. pp. 53-67, IN: Determinants of Soil Loss Tolerance, D.M. Kral (ed.). ASA Special Publ. No. 45, Am. Soc. of Agron. and Soil Sci. Soc. of Am., Madison, Wis.

Klute, A. 1973. Soil water flow theory and its application in field situations. IN: Field Soil Water Regime. Madison: Soil Sci. Soc. Amer. pp. 9-35.

Knapik, L.J. 1973. Alpine soils of the Sunshine area, Canadian Rocky Mountains. M.Sc. thesis. Univ. of Alberta. 231 pp.

Knapik, L.J. 1974. Detailed soil survey of the Canmore area. Alberta Research Council Open File Report 1974-20 (1 map).

Knapik, L.J. 1983. Soil and overburden inventory and reclamation suitability assessment. Gregg River Mine Third Five Year Plan. Report prepared for Gregg river Resources Ltd. by Pedocan Land Evaluation Ltd., Edmonton, Alta.

Knapik, L.J. 1984. Evaluation of soil and overburden quality for reclamation at Coal Valley, Alberta. Report prepared for Luscar Sterco (1977) Ltd. by Pedocan Land Evaluation Ltd., Edmonton, Alta.

Knapik, L.J. and S. Burton. 1980. Soil survey of the coal valley area. Luscar internal working document prepared by Pedology Consultants, Edtn., Alta. Submitted to Gov'T as App. to Revised Appl., Mynheer B Zone, Coal Valley Mine. 76 pp.

Knapik, L.J., G.W. Scotter and W.W. Pettapiece. 1973. Alpine soil and plant community relationships of the Sunshine area, Banff National Park. Arct. and Alp. Res. 5:A161-A170.

Knapik, L.J. and D.A. Westworth. 1982. Ecological Resources of the Calumet Leases, Alberta. Report to Canstar Oil Sands Ltd., Calgary, Alberta.

Knapik, L.J. and D.A. Westworth. 1983. Soil survey of the north half of the Coal Valley lease and ecosystem classification of the Halpenny area. Report prepared for Luscar Sterco (1977) Ltd. by Pedocan Land Evaluation Ltd. 133 pp. + app. and maps.

Knight, H. 1967. Some limiting factors of tree growth in Alberta - a review. Internal Rept. A-8, Can. Dept. of Forestry and Rural Dev., Calgary, Alta. 20 pp. Unpubl. report.

Knight, H., J.A. Schalkwyk, J.R. Prokopchuk, N. Van Waas, E. Boyacioglu and R. Pearson. 1966. Land capability classification for forestry in Alberta. Can. Dept. For. and Rural Dev., Calgary and Alberta For. Serv., Edmonton, Alta. 12 pp. Unpubl. report.

Knudsen, L.L. and P.H. Struthers. 1953. Stripmine reclamation research in Ohio. IN: R.J. Hutnik (ed.) Ecology and reclamation of devastated land. Gordon and Breach, N.Y.

Kohnke, H. 1950. The reclamation of coal mine spoils. Adv. Agron. 2:318-349.

Kohnke, H. and A.R. Bertrand. 1959. Soil Conservation. McGraw-Hill Book Company. Toronto. 298 pp.

Kojima, S. 1984. Forested plant associations of the northern subalpine regions of Alberta. Prepared for Alberta Forest Service, Research Branch, Alberta Energy and Natural Resources by Western Ecological Services (B.C.) Ltd. 135 pp.

Kolar, C.A., W.C. Ashby and G.R. Philo. 1981. Differential performance of trees planted on reclaimed surface mined land. pp. 271-278 IN: Proc.. 1981 Symp. on Surface Mining Hydrology, Sedimentology and Reclamation. Univ. of Kentucky, Lexington, Kentucky.

Koppen, W. 1936. Das geographische system der Klimate. IN: Handbuch der Klimatologie, Vol. I Part C. Berlin, Gebruder Borntraegar.

Krause, H.H., G.F. Weetmand and P.A. Arp. 1978. Nutrient cycling in boreal forest ecosystems of North America. IN: Forest Soils and Land Use. Proc. 5th N. Amer. Forest Soils Conf. Ft. Collins, Colorado. pp. 287-319.

Krumlik, G. 1980. Soil and rooting depth patterns in Northeast Alberta. IN: Workshop on Reconstruction of Forest Soils in Reclamation. Alberta Land Conservation and Reclamation Council, Edtn., Alberta. RRTAC Rep. No. 80-4.

Krumwiede, D.S. 1980. Remote sensing applications as related to surface mining. IN: Proceedings of the 1980 Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. University of Kentucky, College of Engineering, Lexington, Kentucky. Report No. UKY BU123. pp. 159-162.

Langenberg, C.W. and M.E. McMechan. (in press). Lower Cretaceous Luscar group (revised) of the northern and northcentral foothills of Alberta. Bull. of Can. Petroleum Geology.

LaRoi, G.H. and R.J. Hnatiuk. 1980. The Pinus contorta forests of Banff and Jasper National Parks: A study in comparative Synecology and Syntaxonomy. Ecol. Monogr. 50:1-29.

Larson, J.E. 1980. Revegetation equipment catalog. USDA For. Serv. Equipment Development Center, Fort Missoula, Montana. 198 p.

Larson, L. 1980. A survey of techniques for measurement of herbaceous and shrub production, cover and diversity on coal lands in the west. Office of Surface Mining, Region Five, Dept. of Interior. U.S.A.

Lauenroth, W.K., J.L. Dodd, R.K. Heitschmidt, and R.G. Woodmansee. 1975. Biomass dynamics and primary production in mixed prairie grasslands in southeastern Montana. IN: Proceedings of the Ft. Union Coal Field Symposium. Mont. Acad. Sci. East. Mont. Coll., Billings, Mont. pp. 559-578.

Lauenroth, W.K. and W.C. Whitman. 1977. Dynamics of dry matter production in a mixed-grass prairie in western North Dakota. Oecologia (Berl). 27:339-351.

Lea, R. and R. Ballard. 1982. Predicting loblolly pine growth response from N fertilizer, using soil-N availability indices. Soil Sci. Soc. Amer. J. 46:1096-1099.

Lesko, G.L., H.M. Etter, and T.M. Dillon. 1975. Species selection, seedling establishment and early growth on coal mine spoils at Luscar, Alberta. Env. Can. For. Serv., Nor. For. Res. Cent. Edtn., Alta. Info. Rep. NOR-X-117. 37 pp.

Lesko, G.L. and F.D. Lindsay. 1973. Forest/soil relationships and management considerations in a portion of the Chip Lake map area, Alberta. Alta. Res., Edtn. rep. 73-1.

Lieth, H. 1974. Modelling the primary productivity of the world. Intecol Bulletin 4:11-20.

Litton, R.B., Jr. 1968. Forest landscape description and inventories - a basis for land planning and design. USDA For. Serv. Res. Pac. Southwest For. and Rng. Exp. Stn. Berkeley, California. Paper PSW-49, 64 pp.

Longley, R.W. 1970. Climatic classification for Alberta Forestry. IN: Proceedings, Third Forest Microclimate Symposium. Kananaskis For. Exp. Stn., Seebe Alta. Can. Dep. Fish. For. Serv., Alta./Terr. Reg., Calgary, Alta. pp. 147-153.

Lorio, P.L., Jr. and G.E. Gatherum. 1965. Relationship of tree survival and yield to coal-spoil characteristics. Iowa Agric. and Home Econ. Exp. Stn. Res. Bull. 535:394-403.

MacIver, D.C. 1981. The Biogeoclimates of Central and Northern Alberta. Unpublished manuscript.

MacIver, D.C., W.D. Holland, and J.M. Powell. 1972. Delineation of similar summer climatic regimes in central Alberta. Env. Can., Can. For. Serv. North. For. Res. Cen. Edtn., Alta. Info. Rep. NOR-X-30. 32 pp.

MacLean, A.H. 1977. Studies of physical properties of soils and mined minerals in relation to reclamation. IN: Soil Research Related to Revegetation of the Oilsands Area Sub Project VE 4. Dept. of Soil Sci., U. of Alta., Edmonton.

MacLean, E.O. 1977. Contrasting concepts in soil test interpretation: sufficiency levels of available nutrients versus basic cation saturation ratios. pp. 39-54, IN: Soil Testing: Correlating and Interpreting the Analytical Results. Amer. Soc. of Agron. Publ. No. 29. Madison, Wis.

Macyk, T.M. 1972. Interim report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. 20 pp.

Macyk, T.M. 1973a. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alta. AIP Report M-73-14. 35 pp.

Macyk, T.M. 1973b. Soil survey of the No. 9 Mine area, Grande Cache, Alberta. AIP Report M-73-13.

Macyk, T.M. 1974a. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alta. AIP Report M-74-16. 39 pp.

Macyk, T.M. 1974b. Revegetation of strip mined land at No. 8 mine, Grande Cache, Alberta. IN: Proc. of a Workshop on Reclamation of Disturbed Lands in Alberta. Environment Can., Nor. For. Res. Cen. Info. Rep. NOR-X-116. pp. 184-188.

Macyk, T.M. 1977a. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Div. Rep. 41 pp.

Macyk, T.M. 1977b. Progress report, strip mine reclamation project, No. 9 Mine. Grande Cache, Alberta. Alberta Research Council, Soils Div. Rep. 20 pp.

Macyk, T.M. 1978a. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Div. Rep. 36 pp.

Macyk, T.M. 1978b. Progress report, strip mine reclamation project, No. 9 Mine. Grande Cache, Alberta. Alberta Research Council, Soils Div. Rep. 22 pp.

Macyk, T.M. 1979a. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Albverta Research Council, Soils Div. Rep. 21 pp.

Macyk, T.M. 1979b. Progress report, strip mine reclamation project, No. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Div. Rep. 31 pp.

Macyk, T.M. 1980a. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Albeerta Research Council, Soils Dept. Rep. 26 pp.

Macyk, T.M. 1980b. Progress report, strip mine reclamation project, No. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Dept. Rep. 26 pp.

Macyk, T.M. 1981. Progress report, strip mine reclamation project, no. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Dept. Rep. 14 pp.

Macyk, T.M. 1982. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Dept. Report.

Macyk, T.M. 1983. Revegetation studies on fly ash and overburden at Grande Cache. Unpublished Report, RRTAC Proj. No. 79-1-MAC, Land Cons. & Reclam. Coun., Edmonton, Alta. 87 pp.

Macyk, T.M. 1984a. Development of a reclamation technology for the foothill-mountain region of Alberta. IN: Proceedings, 9th Annual m Meeting of Can. Land Recl. Assoc., Calgary, Alta.

Macyk, T.M. 1984b. An agricultural capability rating system for reconstructed soils. IN: Proceedings, 9th Annual Meeting of Can. Land Recl. Assoc., Calgary, Alta.

Macyk, T.M. and J. Steward. 1977. Reclamation at McIntyre No. 8 Mine. IN: Coal Industry Reclamation Symposium, Banff, Alta. 13 pp.

Macyk, T.M. and Z.W. Widtman. 1983. Progress report-surface mine reclamation project, No. 8 & No. 9 mines, Grande Cache, Alberta. Alta. Res. Coun., Edtn., Alta.

Mains, G. 1977. Nutrient cycling and recreating a natural soil and biological system. IN: Proceedings, Coal Industry Reclamation Symposium, Banff. Coal Assoc. of Can. Calgary.

Marshall, R.T. and T.J.R. Godfrey. 1977. Land use planning - the first step in reclamation. IN: Proceedings, Coal Industry Reclamation Symposium, Banff. Coal Assoc. of Can., Calgary. pp. 13-16.

Marx, D.H. 1975. Mycorrhizae and establishment of trees on stripmined land. Ohio J. Sci. 75:288-297.

Marx, D.H. 1980. Role of mycorrhizae in forestation of surface mines. IN: Proceedings, Trees for Reclamation, Lexington, Kentucky. Interstate Mining Compact Comm. and USDA Forest Service. Gen. Tech. Rep. NE-61. pp. 109-116.

McColl, J.G. 1984. Advances in forest soil analysis. IN: Proceedings of the Sixth North American Forest Soils Conference. Dept. of For., Wildlife and Fisheries. Univ. of Tennessee. pp 313-333.

McCool, D.K., M.G. Dossett, and S.J. Yecha. 1981. A portable rill meter for field measurement of soil loss. IN: Erosion and Sediment Transportation Measurement (Proceedings of the Florence Symposium). IAHS Publ. No. 133. pp. 479-484.

McCool, D.K., M. Molnau, R.I. Papendick, and F.L. Brooks. 1976. Erosion research in the dryland grain region of the Pacific Northwest: Recent developments and needs. IN: The Proceedings of a National Conference on Soil Erosion. Purdue University, West Lafayette, Indiana pp. 50-59.

McCoy, D. 1975. Tent Mountain reclamation site. Alberta Dept. of Env., Env. Prot. Serv., Earth Sci. and Licensing Div., Tech. Dev. Branch, Edmonton, Alberta. 10 pp.

McGill, W. 1983. Kinetic effects on quality of soil organic matter. IN: Alberta Soil Sci. Workshop Proceedings. Alta. Agric. Edmonton.

McGill, W.B. and C.V. Cole. 1981. Comparative aspects of organic C, N, S, and P cycling through soil organic matter during pedogenesis. Geoderma 26:(in press).

McGill, W.B. and P.B. Hoyt. 1977. Effect of forages and rotation management of soil organic matter. IN: Soil Conservation Reclamation & Research. Proceedings of Annual Alberta Soil Science Workshop. Alta. Agric., Edtn. Alta. pp. 33-80.

McGinnies, W.J. and P.J. Nicholas. 1980. Effects of topsoil thickness and nitrogen fertilizer on the revegetation of coal mine spoils. J. Environ. Quality 9(4):681-685.

McLean, J.R. 1982. Lithostratigraphy of the Lower Cretaceous coal-bearing sequence, foothills of Alberta. Geological Survey of Canada. Paper 80-29. 46 pp.

McMinn, R.G. 1960. Water relations and forest distribution in the Douglas fir region on Vancouver Island. Canada Dept. of Agric., Pub. 1091.

Merrill, D.D., S.J. Smith and J.F. Power. 1985. Effect of disturbed soil thickness on soil water used and movement under perennial grass. Soil Sci. Soc. Amer. J. 49:196-202.

Merrill, S.D., F.M. Sandoval, J.F. Poer and E.J. Doering. 1980. Salinity and sodicity factors affecting suitability of materials for mined land reclamation. IN: Adequate Reclamation of Mined Lands? Proc. of Symp.; Billings, Montana; Mar. 26-27, 1980. Soil Conservation Soc. of Am. and Western Agric. Exp. St. Coordinating Committee on Mine Waste Reclamation. 25 pp.

Meyer, L.D., W.H. Wischmeier, and G.R. Foster. 1970. Mulch rates required for erosion control on steep slopes. Soil Sci. Soc. Amer. Proc. 34:928-931.

Mihajlovich, M.M. and L. Hall. 1982. Reclamation experiments in the Eastern Slopes of Alberta: RRTAC Project 82-12-TOM. Alberta Forest Service, Alberta Energy and Natural Resources, Edmonton, Alberta.

Minore, D., C.E. Smith and R.F. Woolard. 1969. Effects of high soil density on seedling root growth of several north western tree species. USDA For. Serv. Res. Note, Pac. Nor. West For. and Range Exp. Stn.

Mirreh, H.F. and J.W. Ketcheson. 1972. Influence of soil bulk density and matric pressure on soil resistance to penetration. Can. J. Soil Sci. 52:477-483.

Mitchell, J.K., W.C. Moldenhauer and D.D. Gustavson. 1983. Erodibility of selected reclaimed surface mined soils. IN: Transactions of the American Society of Agric. Eng. pp. 1413-1417 & 1421.

Mitchell, M.L., A.E. Hassan, C.B. Davey and J.D. Gregory. 1981. Effect of soil compaction on root development and seedling establishment. Am. Soc. Agric. Eng. Pap. 81-1040. Orlando, FL. 20 pp.

Mitchell, V.L. 1967. An investigation of certain aspects of tree growth rates in relation to climate in the central Canadian boreal forest. Univ. of Wisconsin. Dept. of Meteorology. Technical Report 33. 62 pp.

Monenco Consultants Ltd. 1983. Soil Reconstruction Design for the Reclamation of Oilsand Tailings Rep[ort. SESG-RRTAC #83-1. 196 pp.

Morgan, K.M. and R. Nalepa. 1982. Application of aerial photographic and computer analysis to the USLE for areawide erosion studies. Journal of Soil & Water Conservation. 37(6):347-350.

Mueller-Dombois, D. 1974. Technique for studying soil-water-growth relations on an artificial slope. pp. 153-161, IN: Forest-Soil Relationships in North America. C.T. Youngberg (ed.). Oregon State Univ. Press, Corvallis, Ore. 532 pp.

Munshower, F.F. 1982. Problems in reclamation planning ad design. IN: Proceedings, Mining and Reclamation of Coal Mined Lands on the Northern Great Plains. Billings MT. Montana Agric. Expt. Sta. Res. Report No. 194.

Munshower, F.F. and S.E. Fisher. 1984. The future of reclamation planning on the Northern Great Plains. IN: Proceedings, Third Biennial Symposium on Surface Coal Mine Reclamation on the Great Plains. Billings, MT.

Murdock, S. 1980. Land use goals vs. reference areas for determining reclamation success. IN: Adequate Reclamation of Mined Lands?--A Symposium. Soil Cons. Society of Amer. and WRCC-21. Billings, MT.

Murray, D.R. 1977. Pit Slope Manual, Supplement 10-1-Reclamation by Vegetation: Vol 1 - Mine Waste Description and Case Histories; CANMET (Canada Centre for Mineral and Energy Technology), CANMET Report 77-31; 120 pp.

Myles, D.V. 1978. A compendium of silvicultural equipment. Information Report FMR-X-115, Forest Management Institute, Canadian Forestry Service, Environment Canada, Ottawa, Ont.

Nicholas, D.J.D. 1965. Influence of the rhizosphere on the mineral nutrition of the plant. IN: Ecology of Soil-Borne Plant Pathogens. (Baker, K.F. and W.C. Snyder, eds.). Univ. Calif. Press, Berkeley. pp. 210-217.

Nielsen, G.A. and F.D. Hole. 1964. Earthworms and the development of coprogenous A1 horizons in forest soils of Wisconsin. Soil Sci. Soc. Am. Proc. 28:426-430.

Nielson, R.F. and H.B. Peterson. 1972. Treatment of mine tailings to promote vegetative stabilization. Utah State Univ., Agric. Exp. St., Logan, Utah. Bull. No. 485. 22 pp. Abstract in Goodman & Bray, 1975.

Nishimura, J.Y. 1974. Soils and soil problems at high altitudes. pp. 5-9, IN: Proc. of a Workshop on Revegetation of High Altitude Disturbed Lands, Fort Collins, Colorado. Info. Series No. 10, Col. State Univ., Fort Collins, Col. 91 pp.

Obed-Mountain Coal Company Ltd. 1984. Development & reclamation plan approval C-4-81 for the period 1984-89. Obed-Marsh Thermal Coal Project. Union Oil Company of Canada Ltd. 13 pp. plus maps.

Ogilvie, R.T. 1976. The alpine and subalpine in the Rocky Mountains of Alberta. IN: H.A. Luttmerding and J.A. Shields (eds.), Proc. Workshop on alpine and subalpine environments, Victoria, B.C., Prov. of British Columbia, Ministry of Environment. pp. 34-46.

Parker, R.W., D. Peters and R.C. Speer. 1983. Soil and overburden inventory ad reclamation suitability assessment Gregg River Mine. Prep. for Gregg River Resources Ltd. by Techman Engineers Ltd. 32 pp. plus append.

Parkinson, D. 1979. Microbes, mycorrhizae and mine spoil. IN: Ecology and Coal Resource Development. Proc. of the Intern. Cong. for Energy and the Ecosystem. Grand Forks, North Dakota. Pergamon Press, Elmsford, NY. pp. 634-642.

Parton, W. and R. Woodmansee. 1980. Ecological considerations in reclamation of disturbed lands. IN: Proc. of the Workshop on Rehabilitation of Disturbed Arid Lands. Utah State Univ., Logan, Utah, pp. 63-78.

Peterson, E.B. and H.M. Etter. 1970. A background for disturbed land reclamation and research in the Rocky Mountain Region of Alberta. Can. For. Service Info. Report A-X-34. 41 pp. plus append.

Peterson, E.B., N.M. Peterson and R.D. Kabzems. 1982. Impact of climatic variation on biomass accumulation in the boreal forest zone: selected references. IN: Proc. of Fourth Bioenergy R&D Seminar, Winnipeg. PP 129-137.

Pettapiece, W.W. 1970. Pedological Investigations in the front ranges of the Rocky Mountains along the North Saskatchewan River Valley. unpub. Ph.D. thesis. Dept. of Soil Sci., Univ. of Alberta. 184 pp.

Pettapiece, W.W. 1971. Land Classification and Soils in the Rocky Mountains of Alberta along the North Saskatchewan River Valley. Alberta Inst. of Ped. No. S-71-31. 39 pp.

Phillips, R.E. and D. Kirkham. 1962. Soil compaction in the field and corn growth. Agron. J. 54:29-34.

Pinchak, B.A., G.E. Schuman and E.J. Depuit. 1985. Topsoil and mulch effects on plant species and community responses of revegetated mined land. J. of Range Mgnt. 38(3):262-265.

Plass, W.T. 1977. Growthy and survival of hardwoods and pine interplanted with European alder. USDA For. Serv. Res. Pap. NE-376. 10 pp.

Powell, J.M. and D.C. MacIver. 1977. A summer climate classification for the forested area of the prairie provinces using factor analysis. Can. For. Rep. NOR-X-177.

Powers, R.F. 1980. Mineralizable soil nitrogen as an index of nitrogen availability to forest trees. Soil Sci. Soc. Am. J. 44:1314-1320.

Pritchard, W.L. 1979. Properties and management of forest soils. John Wiley & Sons, New York, N.Y. 500 pp.

Redente, E.F., T.B. Doerr, C.E. Grygiel, E. Allerdings, D.M. Stark and M.E. Biondine. 1982. Effects of plant species, soil material and cultural practices upon plant establishment and succession. IN: Revegetation Studies on Oil Shale Related Disturbances in Colorado. Res. Rep. DOE/EB/04018-6, Rng. Sci. Dept. Co. State Univ., Ft. Collins, CO. pp. 1-25.

Redente, E.F., C.B. Mount and W.J. Ruzzo. 1982. Vegetation composition and production as affected by soil thickness over retorted soil shale. Reclamation and Revegetation Res. 1:109-122.

Redente, E.F., W.R. Sowards, D.G. Steward and T.L. Ruiter. Editors. 1983. Western Reclamation Group Symposium on Western Coal Mining Regulatory Issues: Land Use, Revegetation, and Management. Colorado State Univ., Range Science Dept. Sci. Ser. No. 35. 110 pp.

Reid, C.P.P. 1984. Mycorrhizae: A root-soil interface in plant nutrition. pp. 29-50. IN: Microbial-Plant Interactions. ASA Special Publ. No. 47, Soil Sci. Soc. of Am., Am. Soc. of Agron. and Crop Sci. Soc. of Am., Madison, Wis. 68 pp.

Richardson, J.L. and N.C. Wollenhaupt. 1983a. Natural soil and landscape development. IN: Can mined land be made better than before mining? Land Recl. Res. Cent. (NDSU). N. Dakota Mining and Mineral Resources Res. Inst. (UND) and N. Dakota Energy Devel. Impact Office, Bismark, N. Dakota. pp. 59-67.

Richardson, J.L. and N.C. Wollenhaupt. 1983b. Water repellancy of degraded lignite in a reclaimed soil. Can. J. Soil Sci. 63:405-407.

Ries, R.E. and L. Hofmann. 1980. Controllig quality of seed present in prairie hay. Paper Presented Before 33rd Annual Meeting, Society for Range Management, San Diego, CA.

Ries, R.E. and L. Hofmann. 1984. Pasture and hayland: measures of reclamation success. IN: Third Biennial Symposium on Surface Coal Mine Reclamation on the Great Plains. Billings, Montana. pp. 307-317.

Riffle, J.W. and M.G. Boosalis. 1979. Mycorrhizae - good for our trees. Farm, Ranch and Home Quarterly, Winter, 1979. Univ. of Nebraska.

Rives, C.S., M.I. Bajwa, A.E. Liberta and R.M. Miller. 1980. Effects of topsoil storage during surface mining on the viability of VA mycorrhiza. Soil Sci. 129:253-257.

Robertson, S., J. Bentz., D. Brierley and S. Nelson. 1984. An Ecosystem Classification for the coal branch. REAP (draft).

Rogowski, A.S. and B.E. Weinrich. 1981. Modeling water flux on strip-mined land. Trans. Amer. Soc. Agric. Eng. 24:935-940.

Root, J.D. 1973. The physical environment of an abandoned strip-mine near Cadomin, Alberta. M.Sc. Thesis. Dept. Geography, Univ. of Alta. Edtn., Alta. 100 pp.

Root, J.D. 1976. Physical environment of an abandoned strip mine near Cadomin, Alta. Alberta Res. Council. Bulletin 34. 33 pp.

Rowell, M.J. 1978. Revegetation and management of tailings sand slopes: 1977 results. Environ. Res. Mon. 1978-5, Syncrude Canada Ltd., Edmonton, Alta.

Rowell, M.J. 1982. Assessment of the soil resource in the reclamation of disturbed mountainous areas. IN: Reclamation in Mountainous Areas. Proc. of the Sixth Annual Meeting of the Can. Land Recl. Assoc. and the Fifth Annual B.C. Mine Recl. Symp. B.C. Min. of Energy, Mines and Petr. Resl, Inspection and Eng. Branch, Victoria. B.C. Paper 1982-2, pp. 241-270.

Ruhe, R.V., T.E. Fenton ad L.L. Ledesma. 1975. Missouri River history, floodplain construction, and soil formations in southwestern Iowa. Iowa Agric. Home Econ. Exp. Stn. Res. Bull. 580:738-791.

Russell, W.B. 1979a. Native grass reclamation research: container plantings in the Eastern slopes of Alberta (1979). Alberta For. Serv., Alta. Ener. & Nat. Resources Rept. No. 140, Edmonton, Alta.

Russell, W.B. 1979b. Survey of native trees and shrubs on disturbed lands in the Eastern slopes. Alberta For. Serv., Alta. Ener. & Nat. Resources, Edmonton, Alta.

Russell, W.B. 1980. The vascular flora and natural vegetation of abandoned coal mined land, Rocky Mountain Foothills, Alberta. Unpubl. M.Sc. thesis, Univ. of Alberta. 96 pp.

Russell, W.B., R. Annas, L.J. Knapik. 1984. Potential natural vegetation data base for Alberta habitat subregions. Report prepared for Alta. Fish and Wildlife Div., by Pedocan Land Evaluation Ltd. 188 pp.

Russell, W.B. and S.K. Takyi. 1979. The Cadomin reclamation research project: First year results (1978). Alberta Forest Service. Alberta Energy and Natural Resources. Edmonton, Alberta. ENR Report No. 121. 47 pp.

Rutter, N.W. 1968. A method for predicting soil erosion in the Rocky Mountain Forest Reserve, Alberta. Geological Survey of Canada, Dept. of Ener., Mines & Res. Paper 67-67. 32 pp.

Sanderson, M. 1948. The climates of Canada according to the new Thornthwaite classification. Sci. Agric. 28:501-517.

Sarles, R.L. and D.M. Emanuel. 1977. Hardwood bark mulch for revegetation and erosion control on drastically disturbed sites. J. of Soil and Water Conservation 32(5):209-214.

Schafer, W.M. 1979. Guides for estimating cover-soil quality and mine soil capability for use in coal stripmine reclamation in the western United States. Reclamation Review 2:67-74.

Schafer, W.M. 1980. New soils on reclaimed land in the Northern Great Plains. IN: Proceedings 1980 Symposium, Adequate Reclamation of Mined Lands? Billings, Mont. Soil Cons. Soc. Amer. and Western Agric. Expt. Station.

Schafer, W.M. 1984. Managing minesoil development for productive reclaimed lands. IN: Proceedings 1984 Canadian Land Reclamation Assoc. Ninth Annual Meeting. Calgary. Alberta.

Schroeder, S.A. and A. Bauer. 1982. Levels and changes in root-zone water in reshaped strip-mined spoils in North Dakota. Agron. Absts., Amer. Soc. of Agronomy, Madison. WI. pp. 256.

Schwab, G.O., R.K. Frevert, T.W. Edminster, and K.K. Barnes. 1981. Soil and Water Conservation Engineering. 2nd edition. John Wiley and Sons, Toronto. 683 pp.

Selner, J. 1973. Surface mine reclamation research in Alberta. Alta. Dept. Lands and Forests. Forest Land Use Branch. Prog. Rep. 50 pp.

Simonson, R.W. 1959. Outlie of a generalized theory of soil genesis. Soil Sci. Soc. Amer. Proc. 23:152-156.

Slatyer, R.O. 1967. Plant-water relationships. Academic Press, London. 366 pp.

Smith, R.M., W.E. Grube, Jr., T. Arkle, Jr., and A. Sobek. 1974. Mine spoil potentials for soil and water quality. Environ. Prot. Technol. Series EPA670/2-74-070. U.S. Environ. Prot. Agency, Cincinnati, Ohio. 303 pp.

Smith, R.M., A.A. Sobek, T. Arkle, Jr., J.C. Sencindiver and J.R. Freeman. 1976. Extensive overburden potentials for soil and water quality. EPA-600/2-76-184. U.S. Env. Protection Agency, Cincinnati, Ohio.

Soil Survey Staff. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, USDA. U.S. Government Printing Office, Washington, D.C.

Spurr, S.H. and B.V. Barnes. 1980. Forest ecology. John Wiley & Sons. New York. 687 pp.

Stallings, J.H. 1957. Soil Conservation. Prentice-Hall, Inc., Engewood Cliffs, N.J. 575 pp.

Stein, O.R., C.B. Roth, W.C. Moldenhauer and D.T. Hahn. 1983. IN: 1983. Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. University of Kentucky, Lexington, Kentucky. pp. 101-106.

Stewart, W.D.P. 1966. Nitrogen fixation in plants. Athlone Press, London. 168 pp.

Stolzy, L.H. and K.P. Barley. 1968. Mechanical resistance encountered by roots entering a compact soil. Soil Sci. 105:297-301.

Stone, E.L. 1984. Site quality and site treatment. IN: Forest Soil and treatment impacts 6th North American Forest Soils Conference Proceedings. pp. 41-52. E.L. Stone, Editor. Univ. of Tenn., Knoxville, Tenn.

Strong, W.L. and G.H. LaRoi. 1983a. Rooting depths and successional development of selected boreal forest communities. Can. J. For. Res. 13:577-588.

Strong, W.L. and G.H. LaRoi. 1983b. Root system morphology of common boreal forest trees in Alberta, Canada. Can. J. of Forest Research. pp. 1164-1173.

Strong, W.L. and K.R. Leggat. 1981. Ecoregions of Alberta. Albeerta ENR, Resource Evaluation and Planning Division. Rep No. 143. 64 pp.

Swanson, N.P., A.R. Dedrick, and H.E. Wealky and H.R. Raise. 1965. Evaluation of mulches for water-erosion control. IN: Transactions of the American Society of Agr. Eng. 8(3):438-440.

Switzer, G.L. and L.E. Nelson. 1972. Nutrient accumulation and cycling in Loblolly pine (Pinus taeda L.) plantation ecosystems: The first twenty years. Proc. Soil Sci. Soc. Am. 36:143-147.

Takyi, S.K. 1980. Influence of roll-out mats and ridging on the establishment of plant cover on an unamended coal spoil. A Progress Report for 1979. ENR Report No. 152. Alberta ENR. 36 pp.

Takyi, S.K. 1981. Methods of establishing native grasses on coal overburden. First Year Report (1980). Alta. Ener. & Nat. Resources, Alta. For. Serv., Edmonton, Alta. 22 pp.

Takyi S.K. 1984a. Plant cover establishment methods on a severe Rocky Mountain Foothills site. ENR Tech. Rept. No. T/66, Alberta Energy and Natural Resources, Edmonton, Alta. 33 pp.

Takyi, S.K. 1984b. Role of topsoil, fertilizers and companion crops in revegetation of two severe sites in the Alberta Foothills and Mountains. ENR Tech. Rept. No. T/67, Alberta Energy and Natural Resources, Edmonton, Alta. 29 pp.

Takyi, S.K. and R.M. Islam. 1984. Performance of native grasses and cultivated legumes and grasses on disturbances in the eastern slopes of the Rockies. ENR Tech. Rept. No. T/68, Alberta Energy and Natural Resources, Edmonton, Alta. 30 pp.

Takyi, S.K. and R.M. Islam. 1985. Maintenance fertilization of a revegetated subalpine coal mine spoil. IN: Proceedings, 21st Alberta Soil Science Workshop. Lethbridge, Alberta.

Takyi, S.K. and W.B. Russell. 1980. The Cadomin Reclamation Research Project second-year results (1979). ENR Rept. No. 155, Alberta Energy and Natural Resources, Edmonton, Alta. 54 pp.

Taylor, H.M., M.G. Huck and B. Klepper. 1972. Root development in relation to soil physical conditions. IN: Optimizing the Soil Physical Environment Toward Greater Crop Yields. Academic Press, New York. pp. 57-78.

Techman Engineering Ltd. 1981. Specialized equipment for Oil Sands reclamation. Prepared for Alsands Project Group. Techman Engineering Ltd., Calgary, Alberta. 212 pp.

Techman Engineering Ltd. 1983. Woody plant establishment and management for Oil Sand mine reclamation. Rep. No. OSESG-RRTAC 83-5. Alberta Land Conservation and Reclamation Council, Edmonton, Alberta. 132 pp.

Thomas, J.W. (ed.). 1979. Wildlife habitats in managed forests-the Blue Mountains of Oregon and Washington. U.S. Dept. of Agric. For. Service Agric. Handbook No. 553.

Thornthwaite, C.W. and J.R. Mather. 1957. Instructions and tables for computing potential evapotranspirations and the water balance. Drexel Institute of Technology, Laboratory of Climatology, Centerton, New Jersey. Pub. in Clim. Vol. X(3) pp. 185-311.

Tisdale, S.L., W.L. Nelson and J.D. Beaton. 1985. Soil fertility and fertilizers. Macmillan Publishing Company, New York. 754 p.

Truog, E. (ed.). 1961. Mineral nutrition of plants. University of Wisconsin Press. Madison, Wisc.

Twardy, A.G. and I.G.W. Corns. 1980. Soil survey and interpretations of the Wapiti Map Area, Alberta. Alberta Research Council. Alberta Institute of Pedology. Bulletin No. 39.

Ugolini, F.C. 1968. Soil development and alder invasion in a recently deglaciated area of Glacier Bay, Alaska. IN: J.M. Trappe, J.F. Franklin, R.F. Tarrant and G.M. Hansen (ed.) Biology of alder. Pac. Northwest For. and Range Exp. Stn., Forest Service, USDA, Portland, Oregon.

USDA Forest Service. 1974a. National forest landscape management, vol. 1. USDA Agric. Handbook 434, Washington, D.C. 77 pp.

USDA Forest Service. 1974b. National Forest landscape management, vol. 2, chap. 1, The visual management system. USDA Agric. Handb. 462, Washington, D.C. 47 pp.

USDA Forest Service. 1976. Equipment development and test program. Equipment and Development Test Board, USDA For. Serv., Washington, D.C. 130 pp.

USDA Forest Service. 1979a. User guide to soils. USDA For. Serv. Gen. Tech. Rep. INT-68, Intermt. For. and Range Exp. Stn. Ogden, Utah. 85 pp.

USDA Forest Service. 1979b. User guide to vegetation. USDA For. Serv. Gen. Tech. Rep. INT-64, Intermt. For. and Range Exp. Stn., Ogden, Utah. 85 pp.

USDA Forest Service. n.d. Ecology and regeneration of Lodgepole pine. USDA Agricultural Handbook 606, Washington, D.C.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dept. of Agriculture. Agric. Handbook No. 60. 159 pp.

Union Oil Company of Canada Ltd. Rescan Coal Holdings Ltd. 1981. Obed-Marsh thermal coal project development and reclamation plan supplemental report. 52 pp. plus append.

VanCleve, K. and L.A. Viereck. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. IN: Forest succession - concepts and applications. Edited by D.C. West and D.B. Botkin. Springer-Verlag, New York. p. 185-211.

van den Driessche, R. 1979. Soil management in Douglas-fir nurseries. IN: Forest soils of the Douglas-fir region. Washington State Univ. Coop. Ext. Serv., Pullman. pp. 278-292.

Van't Woudt, B.D. and R.M. Hagan. 1957. Crop responses to excessively high soil moisture levels. IN: Drainage of Agric. Lands. Madison: Amer. Soc. of Agron. pp. 514-578.

Veihmeyer, F.J. and A.H. Hendrickson. 1948. Soil density and root penetration. Soil Science 65:487-493.

Visser, S., C. Griffiths and D. Parkinson. 1984a. Reinstatement of biological activity in severely disturbed soils: effects of mining on the microbiology of three minesoils after amendation and planting. IN: Soil Microbiology in Land Reclamation. Vol. I - Soil Microbial Development. Alberta Land Cons. and Recl. Council Rept., RRTAC 84-4. 283 pp.

Visser, S., J.C. Zak, R.M. Danielson, C. Griffiths and D. Parkinson. 1984b. Reinstatement of biological activity in severely disturbed soils: effects of different amendments to three different minespoils on selected soil physical and chemical properties and on plant growth. IN: Soil microbiology in Land Reclamation. Vol. I - Soil Microbial Development. Alta. Land Cons. and Recl. Council Rept., RRTAC 84-4. 120 p.

Vogel, W.G. and W.A. Berg. 1968. Grasses and legumes for cover on acid strip-mine spoils. J. of Soil and Water Conserv. 23(3):39-91 Abstract in Ralston et al., 1977.

Vogel, W.G. and W.A. Berg. 1973. Fertilizer and herbaceous cover influence establishment of direct-seeded black locust on coal-mine spoils. R.J. Hutnik and G. Davis (eds.). IN: Ecology and Reclamation of Devastated Land. Proc. of Symp. on the Ecology and Revegetation of Drastically Disturbed Areas: Univ. Park, Pennsylvania: Aug. 3-16, 1969. Gordon and Breach Scientific Publ., New York (1973). pp. 189-198.

Vomocil, J.A. and W.J. Flocker. 1961. Effect of soil compaction on storage and movement of soil air and water. Trans. ASAE 4:242-246.

Wali, M.K. 1980. Succession on mined lands. IN: Adequate Reclamation of Mined Lands?--A Symposium. Soil Conservation Society of America and WRCC-21. Billings, MT. pp. 23:1-23:46.

Walker and Assoc. 1981. Sand stabilization and revegetation trials 1980. Alaska highway gas pipeline project Zone 9 (Saskatchewan). Prepared for Nova, An Alberta Corporation. 105 pp.

Walmsley, M., G. Utzig, T. Vold, D. Moon, J. vanBarneveld (eds). 1980. Describing ecosystems in the field. Province of British Columbia, Ministry of Env. and For., Victoria. RAB Tech. Pap. 2. Land Management Report No. 7. 224 pp.

Watson, L.E., R.W. Parker, and D.F. Polster. 1980. Manual of plant species suitability for reclamation in Alberta. Alta. Cons. and Recl. Coun., Rep. No. RRTAC 80-5.

Weetman, G.F. 1961. The nitrogen cycle in temperate forest stands. Res. Note 21. Pulp Paper Res. Inst. Canada. 28 p.

Weetman, G.F. and R. Fournier. 1982. Graphical diagnoses of lodgepole pine response to fertilization. Soil Sci. Soc. Am. J. 46:1280-1289.

Weetman, G.F., R.C. Yang and I.E. Bella. 1984. Nutrition and fertilization of lodgepole pine. pp. 225-232, IN: Lodgepole Pine, The Species and It's Management. Symp. Prtoc., D.M. Baumgartner, R.G. Krebill, J.T. Arnott and G.F. Weetman (eds.). Cooperative Extension Service, Washington State Univ., Pullman, Wash.

Welch, R., T.R. Jordon, and A.W. Thomas. 1984. A photogrammetric technique for measuring soil erosion. IN: Journal of Soil & Water Conservation. 39(3):191-194.

Wilde, S.A. 1946. Soil Fertility standards for game food plants. J. Wildlite Man. 10(2):77-81.

Wilde, S.A. 1958. Forest soils. The Ronald Press Company, New York. 537 pp.

Wilde, S.A., J.G. Iyer, C. Tanzer, W.L. Trautmann and G.K. Watterston. 1965. Growth of Wisconsin coniferous plantations in relation to soils. Res. Bull. 262, Univ. of Wis., Madison, Wis. 80 pp.

Wilde, S.A. 1966. Soil Standards for plantng Wisconsin conifers. J. For. 64:389-391.

Wilde, S.A., B.H. Shaw and A.W. Fedkenheuer. 1968. Weeds as a factor depressing forest growth. Weed Res. 8(3):196-204.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses--a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

Woolenhaupt, N.C. and J.L. Richardson. 1982. The role of topography in revegetation of disturbed lands. IN: Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains. Montana Agric. Exp. Stn. Res. Report No. 194. 11 pp.

Wollenhaupt, N.C. and J.L. Richardson. 1983. Planning the post-mining landforms for optimum use of available soil material. IN: Can mined lands be made better than before mining? Land Reclamation Res. Center (NDSU). N. Dakota Mining and Mineral Resources Res. Inst. (UND) and N. Dakota Energy Development Impact Office, Bismark, N. Dakota. pp. 69-76.

Wollum, A.G. and C.B. Davey. 1975. Nitrogen accmulation, transformation, and transport in forest soils. pp. 67-106. IN: Forest Soils and Forest Land Management, B. Bernier and C.H. Winget (eds.). Les Presses de l'Universite Laval, Que.

Zak, J., C. Griffiths and D. Parkinson. 1984. Reinstatement of biological activity in severely disturbed soils: vesicular-arbuscular mycorrhizal development of slender wheatgrass on amended oil sand tailings and subalpine coal mine spoil. IN: Soil Microbiology in Land Reclamation. Vol. II - Mycorrhizae. Alberta Land Conservation and Reclamation Council Report, RRTAC 84-4. 58 pp.

Ziemkiewicz, P.F. 1979a. Effects of fertilization on the nutrient and organic matter dynamics of reclaimed coal-mined areas and native grasslands in southeastern B.C. Unpub. Ph.D. Thesis. Faculty of For., Univ. of B.C.

Ziemkiewicz, P.F. 1979b. The capacity of reclamation plant communities to supply their own nutrients: When does maintenance fertilization become unneccessary? IN: Proceedings of Can. Land Recl. Assoc. 4th Ann. Meeting, Regina, Sask. pp. 195-205.

Ziemkiewicz, P.F. 1982. Determination of nutrient recycling capacity of two reclaimed coal mine sites in British Columbia. Recl. and Reveg. Res. 1:51-61.

Ziemkiewicz, P.F., S.K. Takyi, and H. Regier (eds). 1980. IN: Proceedings: Workshop on reconstruction of forest soils in reclamation. Alberta Land Conservation Council Report No. RRTAC 80-4.